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EARLY SCIENCE IN OXFORD

PART I—CHEMISTRY

BY

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MAGDALEN COLLEGE, OXFORD

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TO

MY COLLEGE PUPILS

THIS FIRST ATTEMPT

AT A HISTORY OF THE EARLY SCIENTIFIC STUDIES

AT THEIR UNIVERSITY

IS DEDICATED

PREFACE

This account of early science in Oxford is a first attempt to bring together such scattered information as is relevant to a fuller history of the progress of science. Now, while the main outlines of the work of some investigators, such as Boyle, on the properties of gases and on the chemical elements, or Harvey on the circulation of the blood and on generation, are familiar to all, the achievements, indeed the very names, of many early distinguished men of science belonging to Oxford are comparatively unknown. Digges, Recorde, Dwight, Lower, Mayow, and many another are forgotten by all but the few who specialise in the history of science. Their works are absent even from their own College Libraries. Yet these were the men who went further than their contemporaries to advance natural knowledge in this country. The achievements of these and others include such fundamental inventions as the construction of telescopes, the production of salt-glaze and special porcelains, the power-loom, the common symbols of calculation and the bringing of them into common use. Few people are acquainted with Sir Christopher Wren as a physiologist or as being on a par with Newton as a mechanician. And, if so little regard is had of these who are only a few generations removed from us, is it surprising that the names of the pioneers of the earlier centuries, such as Tunstal, Richard of Walling-

ford, Merle, Mauduit, Rede and Aschenden should be met only in the works of the archæologists?

A feature of the forthcoming parts of this book will be a *catalogue raisonné* of some of the scientific instruments with which man has explored space. Oxford is rich in specimens of the best work of the leading English instrument-makers of the seventeenth and eighteenth centuries. Examples were lent by various Colleges and University Departments for exhibition at the Bodleian Library in the summer of 1919. They have mostly been photographed, and it was the plan both of Sir William Osler and of the author that the Catalogue of that Exhibition should form the basis of a more comprehensive work dealing with the history of science from the instrumental side.

The very wealth of the material, however, led to the postponement of the plan. The Clarendon Press, overloaded with the history of the English language, and snowed under by the printing of official papers, has been unable to undertake a work of local interest. This first instalment, dealing with Chemistry, has been issued because it required but few illustrations of apparatus. It will be followed by Part II on Mathematics, but Part III on Astronomy, and later parts, must wait until a sufficient subscription list has been obtained to lessen the loss on production at the high prices ruling at the present time.

For the illustrations special thanks must be given to the Council of the Royal Society for the loan of Sir William Huggins's blocks, now the property of the Society; to Messrs. Macmillan for permitting me to have their blocks of figs. 3–9 electrotyped. Special help has been received from my friends Mr. Hadley and Major Walden: the former has explained the meaning of certain passages in the obscure Latin of Borrichius and the merits of the elder Dr. Wall, while the latter

has not only read through most of the proof-sheets, but has lent an original print by Rowlandson for the illustration of a chemical lecture of the last century.

To these, to all my friends in the Bodleian and Ashmolean, to Mr. J. Manley, and to Mr. Poole of the Archives, my best thanks.

R. T. GUNTHER.

1 *May*, 1920.

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EARLY SCIENCE IN OXFORD

PART I—CHEMISTRY

I

THE BEGINNINGS

Roger Bacon, 1214—June 11, 1292

These records of the study of natural science in Oxford, but for the outbreak of war, would have been printed in 1914, when, in the year of the commemoration of his seven hundredth anniversary, a few notes on Roger Bacon came aptly as a beginning.

He discovered, and was the first to teach, the only true method by which the advancement of scientific learning can be effected, namely, the method of experimental science.

SINE EXPERIENTIA NIHIL SUFFICIENTER SCIRI POTEST

This, Roger Bacon's own dictum, enunciating the principle that distinguishes true science from false, was chosen for its fitness to be placed over the entrance to an Oxford laboratory, when the Daubeny building was enlarged in 1902. And rightly, for in a chemical laboratory his name should come before all others, as it is to the application of experiment to Alchemy, "the lord of all sciences and the end of all speculation," that we owe the whole science of chemistry.

Several who have read his pregnant words ascribe them to Francis Bacon,[1] and are surprised to learn that they were written three centuries earlier by his great

[1] Lord Bacon enunciated a similar view in his Aphorisms on the Interpretation of Nature and the Kingdom of Man, *Novum Organon*, 1620.

namesake of Oxford. Roger was at once the earliest and among the greatest of our teachers, and we in Oxford should honour his memory all the more, in that, though trammelled by the Church, he did not let her fetter his genius.

He clearly distinguished between "speculative alchemy" and "practical alchemy." Unlike his contemporaries, he would have nothing to do with occult phenomena. He strongly condemned "the damnable practice of calling up wicked spirits," while he extolled the practical and useful side of knowledge. "The utility of everything must be considered." Practical chemistry is more important than the other sciences, because "it is productive of more advantages" than they.

Chemists have rarely received such praise, indeed the majority of Bacon's contemporaries would probably have agreed with Leo Africanus [1] in regarding them as "a most stupid set of men who contaminate themselves with sulphur and other horrible stinks." Bacon took higher ground: he realised that without real practical acquaintance with laboratory methods, it was fruitless to try to prepare metals and colours and other useful chemical substances.

He, too, was the first to insist on chemistry as necessary to the training of a physician, thus foreshadowing the curriculum of modern medical schools. He had seen the doctors of his time commit many errors owing to ignorance of chemistry; the knowledge of how to distil properly, to sublime, and to calcinate, of how to separate ingredients—laboratory training, in short—must become, he realised, an essential preliminary to the study of medicine.

Many, who have criticised his position as a chemist from the more advanced standpoint of modern science, have taken him less seriously than he deserves, on account of the frequent inconsistencies in his chemical writings. Two points should, however, be borne in mind.

Firstly, he was limited by the phraseology of his time, by the allegory of the alchemists, and by the

[1] *Descriptio totius Africæ*, iii. *Alchymistæ* [of Fez].

dominance of the Greek philosophy, that matter is composed of the four elements, earth, fire, air, water.

Secondly, for his 'facts' about many chemical processes, he relied upon the fantastic descriptions of expert alchemists. It is only fair to him to suppose that, had he been able to carry out his own great principle and to repeat their experiments himself, his *De Arte Chymiæ* would have been as celebrated for its descriptions of chemical operations as are certain other of his books for their lofty conceptions of physical science.

The name of Bacon was associated with some Oxford traditions, and several localities have been pointed out as his 'studies' or 'observatories.' Hearne records that "what he did in Chymistry was carried on by him in places more private, sometimes in the Suburbs . . . in which there was also a fine Grove of trees, now a bare Meadow, and sometimes at Sunningwell."

Early Apothecaries

In an account of the materials necessary for chemical and medical studies, and of the sources whence they were derived, some mention must be made of the predecessors of the vendors of *materia medica* from whom in after years the early experimentalists derived some of their most precious chemicals.

At first apothecaries' shops were almost exclusively stocked with remedies prepared from plants. The Arabians made the process of distillation serviceable for this purpose, and thus distilled water, ethereal oils, and spirit of wine (a potent remedy, the *aqua vitæ* of the alchemists) came into general use. Saltpetre and mercury in the form of grey ointment were true chemical preparations.

These apothecaries' shops, with their fittings, sprang up in Spain, Southern Italy (in Salerno in the eleventh century), and somewhat later in Germany.

In medieval Oxford the Spiceria, or place or shops where spices, seeds, and certain roots were sold, was situated in the High Street near the site of the present

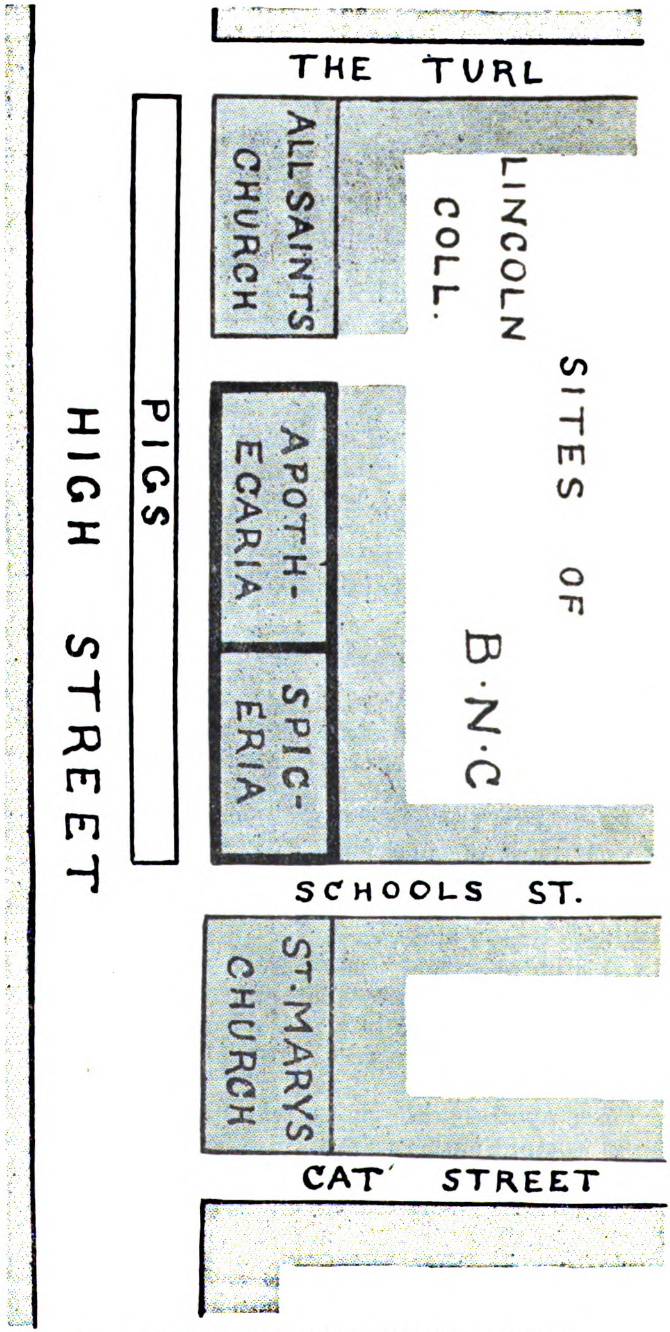


FIG. 1.—THE APOTHECARIES' QUARTER IN OXFORD.

front of Brasenose College. Wood, from whom we derive our information, refutes the claim of one Johannes Falcandus of Lucca (*c.* 1357) and of London to be the first apothecary in England by finding that John le Spicer mentions a certain seld situated in All Saints Parish *in ypothecaria* in 1332. " From the houses opposite to the north-east corner of All Saints' Church-yard where the backway to the Phœnix Inn is, and soe to the High Street, wee find anciently to be called the *apothecaria et spiceria.*" When the trade was first established in Oxford Wood does not know, but notes that it seemed to have been from the first under the jurisdiction of the Chancellor.

The spiceria seems for the most part to have belonged to St. John's Hospital, which " also receiveth from a certain hous with a seld neare to the seld of William le Spicer in the espycery in the parish of All Saints 2 marks."

The spice shops were 'ragged' in the reign of Henry III " by the schollers of Oxon in a conflict betweene them and the townsmen. Heare the old rithems of Robert of Gloucester :

> "'In the south halfe of the towne, and suth the spicerie
> Hii breke from end to other, and dude all to robberie.'"

Probably here, as in the Kingdom of Sicily, no qualified physician was permitted to be in partnership with an apothecary or to keep an apothecary's shop. By the statute of Frederick II *De Medicis*, apothecaries were to compound their drugs at their own expense, which was to be certified by a medical man, and were to take oath that they would compound them according to the prescribed forms. (Cholmeley, *John of Gaddesden.*)

All that these early pharmacists put into their prescriptions has naturally not been put upon record, but no doubt there were periods in their history when one might have written over their pharmacy door :

> "HIC VENDITUR GALBANUM, ELATERIUM, OPIUM,
> ET OMNE QUOD IN UM DESINIT NISI REMEDIUM."

But for all that there was probably a very good tacit understanding between the doctors and the apothecaries. The author of the *Rosa Anglica*, early in the fourteenth century, recommends perfumes, washes, and hair-dyes for the ladies, and prescribes not only the most expensive medicaments for them, but also *double* the dose that would cure a poor patient.

Pharmacy Pots

Since the material aspect of the study of the sciences is the principal object of this book, we must also, while mentioning the pharmacies, not forget the receptacles in which drugs were preserved in those early days.

The art of glazing earthenware vessels was in Europe no doubt a by-product of alchemical research of considerable antiquity. The use of the fine white enamel glaze yielded by tin oxide is in Italy first associated with the name of Luca della Robbia (1400–81).

Our early drug jars are generally considered to be Italian. Only in the seventeenth century did the Dutch commence to make Delft ware.

Fragments of drug jars of all sizes have been found on many sites in Oxford. We figure a few from the series in the Ashmolean Museum.

My friend Mr. Bell informs me that the older decorated examples may very possibly have been manufactured at Bristol, which for many years had been the port by which almost all foreign pottery and glass entered the country.

FIG. 2.—DRUG-JARS EXCAVATED IN OXFORD

6]

II

EARLY LABORATORIES

1645—1668

"Dobbiamo comminciare dall' esperienza e per mezzo di questa scoprire la ragione."—L. DA VINCI.

IT is a moot point whether Roger Bacon really made much impression on his contemporaries; if any, it was evanescent; and in the succeeding centuries Oxford savants continued to wander in a maze of arbitrary figments and partial inductions, in which experimental science found no place. The study of natural phenomena was foreign to academic learning, and without recourse to nature no progress in science or philosophy was possible. At academic disputations, "the same knots were tied and untied: the same clouds were formed and dissipated" (Whewell) by book-learned scholars who contemned studies that were practical. The long list of Waynflete readers of Natural Philosophy, none of whom left any original work, shows how barren discourses on this subject must be, when they are founded on Aristotle [1] rather than on Nature.

That the educated public was acquainted with Greek views on the constitution of matter is indicated by a verse of Ben Jonson:

> . . . Those Atomi ridiculous
> Whereof old Democrite and Hill Nicholis
> One said, the other swore, the world consists.
> *Epigrams* (134).

Nicholas Hill was a Fellow of St. John's College (*circ.* 1570?–1610), and a contemporary of R. FLUDD, the Rosicrucian, of St. John's 1591, of Christ Church

[1] Much later, at the ceremony for taking the B.A. degree, the student, when formally asked the heads of the predicables, formally replied, *Aristoteles pro me respondebit.* (Wordsworth, *Scholæ Academicæ*, p. 124.)

c. 1605, and therefore considerably junior to the Magdalen alchemists, Simon Forman and John Thornborough, author of *Λιθοθεωρικὸς* (1602).

This dark period, which preceded the dawn of science in our own country, produced in Italy the greatest physicist of the fifteenth century, Leonardo da Vinci, whose influence would have been far-reaching had his manuscripts been given to the world; for he was in many respects a forerunner of Francis Bacon and in practical matters greatly his superior.

It was not till the early years of the seventeenth century that Englishmen began to turn their attention to Experiment as a means of investigating physical problems, and again, as in Bacon's time, the impetus was given by Italian men of science, some of whom, like Galileo and Giordano Bruno, suffered persecution or martyrdom for their conclusions.

Travellers brought back new ideas and new knowledge. We may mention Sir Henry Wotton (1568–1639), who, at the age of sixteen, had entered as a commoner at New College, but migrated to Queen's College two years later. He retained an interest in science throughout life. In 1620 he communicated an account of experiments witnessed in Kepler's house at Linz to Bacon, and in 1622 he wrote to Charles, Prince of Wales, about philosophical experiments seen at Venice. Izaak Walton [1] consulted him on the ingredients of strong smelling oils which proved seductive to fish. He discussed distillings from vegetables for medical purposes with Sir Edmund Bacon,[2] and he experimented on the measurement of small divisions of time by the descent of drops of water through a filter.[3]

An early Oxford distiller of this period was Dr. JOHN FRENCH (1616 ?–1657) a native of Oxfordshire, who took his M.A. from New Inn Hall, and was the author of several treatises on distillation. These were "partly taken out of the most select Chymicall Authors of several Languages, and partly out of the Author's manuall experience." He died as one of the two

[1] *Compleat Angler*, 1653. [2] *Reliquiæ*, pp. 454–6.
[3] *Ib.*, p. 475.

physicians to the whole of the English Army in France in 1657.

New workers felt the quickening effect of discussions at the meetings of scientific societies which were founded on Italian models, though the first suggestion of them in England is said to have been made by Theodore Haak, "a German of the Palatinate, then resident in London" (Wallis).[1]

The earliest meetings of which we have record were held in London in 1645. The discourse was generally on recent discoveries such as comets, new stars, Jupiter's satellites, vacuities, descent of falling bodies. The meetings were held sometimes at Doctor Goddard's lodgings in Wood Street, because he kept an operator in his house for grinding glasses for telescopes and microscopes, sometimes at the Bull Head tavern in Cheapside, and sometimes at Gresham College.

The troubles of the Civil War brought Dr. John Wilkins and others who had regularly attended the London meetings, to Oxford in 1649, and once again Oxford became for a few years the centre of all that was greatest in English science. Here Dr. Wilkins, with Seth Ward, Ralph Bathurst, Dr. Petty,[2] Dr. Willis, and others, held weekly an "experimentall philosophicall clubbe" and "brought those studies into fashion there; meeting first at Dr. Petty's (in an apothecaries house) because of the convenience of inspecting drugs, and the like, as there was occasion; and after his remove to Ireland (though not so constantly), at the lodgings of Dr. Wilkins, then Warden of Wadham College, and after his removal to Trinity College in Cambridge, at the lodgings of the Honourable Mr. ROBERT BOYLE."

Boyle, a young nobleman of twenty-eight years of age, having been born in the year of Bacon's death, was not at that time a member of the University,[3] but

[1] Th. Haak (*b.* Neuhausen 1605, *d.* London, 1690) became a member of Gloucester Hall in 1629. His portrait is in the Bodleian Library.

[2] In 164– Sir William Petty (*b.* 1623, *d.* 1687) "came to Oxford, and entred himself of Brasen-nose College. Here, beloved by all the ingeniose, he taught anatomy to the young scholars." (Aubrey.) He became D.Ph. in 1649.

[3] The degree of Doctor of Physick was conferred upon Boyle in 1665.

had been attracted by the reputation of the Oxford Experimental Philosophers. It was said of him in after years that—

"His greatest delight is chymistrey. He haz at his sister's a noble laboratory, and severall servants (prentices to him) to looke to it. He is charitable to ingeniose men that are in want, and foreigne chymists have had large proofe of his bountie, for he will not spare for cost to gett any rare secret." Experiment, he declared, is the interrogation of Nature.

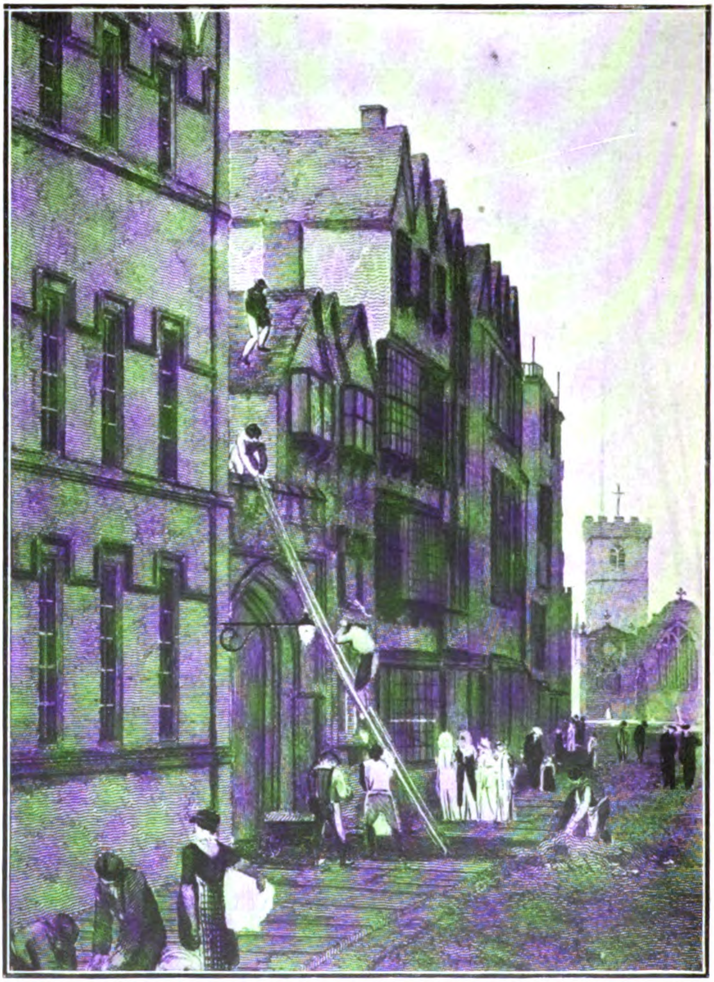
In the circumstances that had preceded his coming to Oxford he had been unlucky. His attempts to fit up a laboratory in Ireland had failed. His friend and teacher, Dr. Petty, had doubtless contrasted the barbarism of Dublin with the opportunities that Oxford afforded.

He had also previously experienced a great disappointment in attempting to fit up a laboratory in his Dorsetshire manor.

"STALBRIDGE,
March 6, 1646–7.

". . . That great earthen furnace, whose conveying hither has taken up so much of my care, and concerning which I made bold very lately to trouble you, since I last did so, has been brought to my hands crumbled into as many pieces, as we into sects; and all the fine experiments and castles in the air, I had built upon its safe arrival, have felt the fate of their foundation. Well, I see I am not designed to the finding out the philosophers' stone, I have been so unlucky in my first attempts at chemistry. My limbecks, recipients and other glasses have escaped indeed the misfortune of their incendiary, but are now, through the miscarriage of that grand implement of Vulcan, as useless to me, as good parts to salvation without the fire of zeal. Seriously, madam, after all the pains I have taken, and the precautions I have used, to prevent this furnace the disaster of its predecessors, to have it transported a thousand miles by land, that I may after all this receive it broken, is a defeat, that nothing could recompence, but that rare lesson it teaches me, how brittle that happiness is, that we build upon earth."

HON. ROBERT BOYLE.
By F Kerseboom.



Univ. Coll. Crosse's. Three Tuns. Tillyard's.

SITE OF BOYLE'S LABORATORY.

In spite of this disappointment his perseverance was fully rewarded. He was the first to prepare hydrogen, and to distinguish between a compound and a mixture, and he wrote in 1649, " Vulcan has so transported and bewitched me as to make me fancy my laboratory a kind of Elysium."

His business required his presence (1652–3) in Ireland, " a barbarous country, where chemical spirits were so misunderstood, and chemical instruments so unprocurable, that it was hard to have any Hermetic thoughts in it." For this reason he gave up chemistry for the time, and began learning to dissect living animals under Dr. Petty's guidance in Dublin. He satisfied himself of the truth of Harvey's discovery of the circulation of the blood, of the newly discovered *receptaculum chyli*, and made many dissections of fishes.

On September 6, 1653, he received an invitation to Oxford from Wilkins in the following terms:

" WADHAM COLLEGE,
" *September* 6, 1653.

" . . . I should exceedingly rejoice in your being stayed in England this winter, and the advantage of your conversation at Oxford, where you will be a means to quicken and direct us in our enquiries. And though a person so well accomplished as yourself, cannot expect to learn anything amongst pedants, yet you will here meet with divers persons, who will truly love and honour you. . . . I shall be most ready to provide the best accommodations for you. . . .

" JO. WILKINS."

So warm an invitation was not to be refused, especially as at Dublin, as he complained in a letter to Dr. Clodius, " I want glasses and furnaces to make a chemical analysis of inanimate bodies." The favourable impression of Oxford he received on his visit, determined him to make a prolonged stay there, and his sister, Lady Ranelagh, came up to settle him in lodgings.

" *October* 12, 1653.

" MY BROTHER,

" It has pleased God to bring us safe to Oxford, and I am lodged at Mr. Crosse's, with design to be able to give

you from experience an account, which is the warmest room; and indeed I am satisfied with neither of them, as to that point, because the doors are placed so just by the chimnies, that if you have the benefit of the fire you must venture having the inconvenience of the wind, which yet may be helped in either by a folding-screen, and then I think that which looks into the garden will be the most comfortable, though he have new hanged and intends to matt that you were in before.

"Yours affectionately and constantly,

"K. R(ANELAGH)."

By June 1654 he was settled in Crosse's rooms in the High Street on the west side of University College, and there fitted up the laboratory in which he worked until 1668. Crosse's house, formerly Deep Hall, was where the Shelley Memorial now stands; with Staunton Hall it was pulled down in 1809 and the site was partly occupied by Sir Ch. Barry's New Building in 1842. After the departure of Dr. Wilkins, the Oxford experimentalists and their friends gravitated to Boyle's Lodgings and to Arthur Tillyard's house, now No. 90 High Street, next door but one. The house between the two was the Three Tuns Inn, lately the house of the Master of University College.

"In this yeare, 1655, Arth. Tillyard, apothecary and great royallist, sold coffey publicly in his house against [= opposite] All Soules Coll. He was encouraged so to do by some royallists now living in Oxon and by others, who esteem'd themselves either virtuosi or wits; of which the chiefest number were of Alls. Coll., as Peter Pett, Thom. Millington [afterwards an eminent physician and a knight], Tim. Baldwin, Christop. Wren, George Castle, Will. Bull, &c. There were others also, as Joh. Lamphire, a physician lately ejected from New Coll., who was sometimes the natural droll of the company, the two Wrens, sojourners in Oxon, Matthew and Thomas, sons of Dr. Wren, bishop of Ely, &c." (Wood, *Life*.)

Dr. Thomas Willis, too, "studied chymistry in Peckwater Inne chamber," and with such practical result, that when in 1657 he noticed a spring which discoloured

stones of a kind of *crocus Martis* colour, "he getts gaules,[1] and putts some of the powder into the water, and immediately it turns blackish; then sayd he 'I'le not send my patients now so far as Tunbridge'" (Aubrey).

Apparatus and Chemicals

Before the middle of the seventeenth century the entire scientific equipment in the University was probably limited to a few dials and astronomical instruments, and to the terrestrial and celestial globes which are still furniture of college libraries.

As a rule these early philosophers required no specially equipped apartments for their work. Their apparatus was probably of a portable and popular nature. Thomas Allen "had a great many mathematical instruments and glasses in his chamber" at Gloucester Hall, where he resided for sixty years until his death in 1632; "the vulgar did verily believe him to be a conjurer," but his books, presented to the Bodleian Library in 1632, contain more information respecting the scientific work of the early Oxford school than any other collection. A "store of mathematical instruments, chiefly given by the late Archbishop Laud" was kept in St. John's College Library (*Evelyn*, 1654). The natural history specimens in the Anatomy school will be described later. The most considerable collection of instruments was to be seen at the Warden's lodgings at Wadham, where it was shown to Evelyn in 1654.

"*July* 13.—We all dined at that most obliging and universally-curious Dr. Wilkins,[2] at Wadham College."

[1] A test for iron that had been used by the iatrochemists from the time of Paracelsus.

[2] "He was the first who showed me the transparent apiaries, which he had built like castles and palaces, and so ordered them one upon another, as to take the honey without destroying the bees. These were adorned with a variety of dials, little statues, vanes, etc.; and, he was so abundantly civil, finding me pleased with them, to present me with one of the hives which he had empty, and which I afterwards had in my garden at Sayes Court, where it continued many years, and which his Majesty came on purpose to see and contemplate with much satisfaction. He had also contrived a hollow statue, which gave a voice and uttered words by a long concealed pipe that went to its mouth, whilst one speaks through it at a good distance." (Evelyn, *Diary*.)

He had above in his lodgings and gallery, variety of shadows, dials, perspectives and many other artificial, mathematical, and magical curiosities, a way-wiser, a thermometer, a monstrous magnet, conic and other sections, a balance on a demi-circle; most of them belonging to himself, and to that prodigious young scholar Mr. Christopher Wren. From other sources we know that Wilkins also possessed a great telescope [1] and a 'rare burninge glasse,' a source of heat employed by many chemists from Paracelsus to Priestley, and that Christopher Wren had a barometer; but the inquiries of Robert Boyle were on a more elaborate scale, and with the advance in the study of the New Philosophy the requisite instruments and rooms for their use became a necessity.

Plans for the building, equipment, and endowment of laboratories for scientific research were being much discussed at that time. Francis Bacon, in the *New Atlantis*, had already formulated the idea of a National Research Laboratory on a large scale; and Boyle, shortly before coming to Oxford, had received a letter on the same subject from Hartlib, proposing an Institute of Science at Vauxhall. Again, ten years later, Evelyn put before Boyle a very comprehensive scheme for an Institution for the Investigation of Science, in which "there should likewise be an elaboratory with a repository for rarities and things of Nature. . . . One month in spring, a course in the elaboratory on vegetables, etc. In winter, a month on other experiments."

Cowley, at about the same time, made a somewhat similar "Proposition for the Advancement of Experimental Philosophy."

Thanks to the detailed though scattered entries in Wood's diaries it is possible to follow the early stages in the spread of the new laboratory learning, and to reconstruct the first classes held. The facts are stated in Wood's own words:

"1649–59. The Royall Societie at Oxon [2] did in

[1] Wilkins left his telescope to Queen's College library when he went to Cambridge (Barlow, Letter of September 13, 1659).

[2] *Sic* Wood. The Royal Society was founded in 1662.

Clerk's house, an apothecary in St. Marie's parish, exercise themselves in some chimicall extracts, which were carried on and much improved before the king's restauration, in so much that severall scholars had privat elaboratories and did performe those things which the memory of man could not reach. But the one man that did publickly teach it to the scholars was one Peter Sthael. . . ." "The practise of chymistry is a piece of knowledge not mis-becoming a gentleman." (Wallis).

Boyle's laboratory proved a valuable incentive to students of the new science, and several important communications to the Royal Society were the result of research done in it.

In these researches Boyle was helped by several paid assistants, of whom the ingenious Robert Hooke [1] is the best remembered; he it was who made the celebrated air-pump, and, by permission of his patron, took up the duties of "Curator of Experiments" to the Royal Society in the second year of its existence. Even then he still continued to assist Boyle with instruments, as his letters show.

"I hope you received the ball and socket" (November 10, 1664).

"I did last week send down by Moor's waggon a weather glass poised upon its centres" (Letter of July 8, 1665).

"I have given Mr. Shortgrave directions for making of a wheel baroscope for you by a new way" (March 21, 1665–6).

It is not an easy matter to decide which of Boyle's researches were actually accomplished in his Oxford laboratory, and which were carried out elsewhere. But we know that the first product of this eventful period was his pneumatical engine or air-pump, and that its fame had reached Paris by 1660, and that it had led to a number of subsidiary experiments and discoveries, such as those on the 'spring,' or elasticity of the air, the sealing of "glasses hermetically, when, without the

[1] Robert Hooke, *b.* Freshwater 1653, *d.* 1703, was a member of Christ Church who acted as assistant first to Willis, and then to Boyle.

help of heat (for it is done by the engine) they are more exhausted of air than an Æoli-pile has been yet brought to be by the help of heat. And this I have actually done, and that by several ways." (Letter of October 26, 1667.) Other experiments were on the burning of bodies *in vacuo*, in which he may have made use of the burning-glass of 10 in. diameter mentioned September 8, 1665. It is recorded that on one occasion his 'hermetically sealed' glasses burst when he heated minium contained in them by a burning-glass. Then there were the experiments on which his *Thermometrical Discourse and History of Cold* were based (1664).

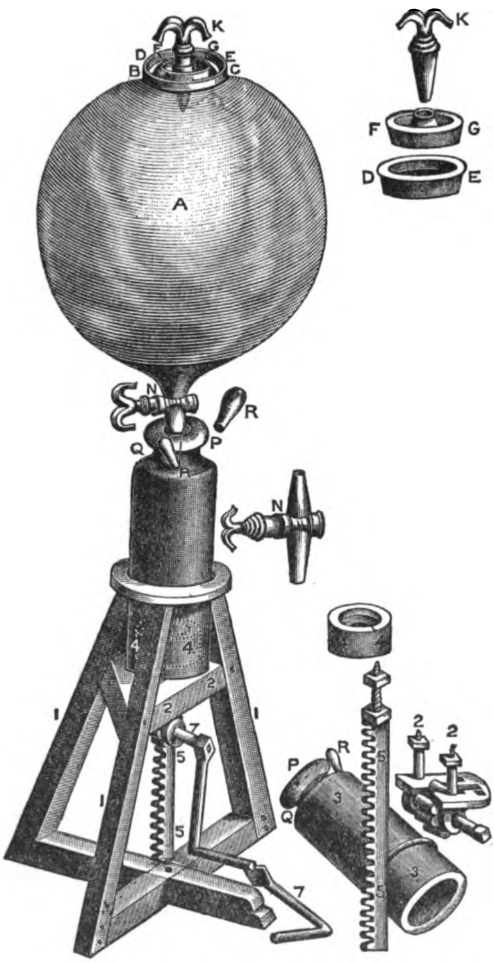


FIG. 3.—BOYLE'S PNEUMATIC ENGINE, OR AIR-PUMP.
As used in his Laboratory in the High Street in Oxford in 1660.

In chemistry, his chief treatise, *The Sceptical Chemist: or Chymico-physical Doubts and Paradoxes touching the*

Experiments, whereby vulgar Spagyrists are wont to endeavour to evince their Salt, Sulphur and Mercury,[1] *to be the true Principles of Things*, appeared at Oxford in 1661. It is one of the great classics of chemical science, because in it Boyle first gave to the word "element" its modern meaning, viz. elements are those primitive and simple bodies, of which the mixed ones are composed, and into which they are ultimately resolved. Moreover, he particularly insisted that the number of the elements must be settled by experiments rather than by abstract reasoning. No other chemical treatise of the day contained as many well-authenticated facts, many of which, such as the production of methyl alcohol from the products of the destructive distillation of wood, and that of acetone from the acetates of lead and lime heated together, were discoveries made by Boyle himself. (Cf. Thorpe's *Essays.*)

In 1668 he published his *Experiments on Colours*, in which he described the well-known action of acids and alkalies on vegetable colouring matters, such as the blue extract of "*Lignum nephriticum*, a syrup of violets and cornflowers and the purple juice of ripe privet-berries."

His work on *Noctiluca*, or Phosphorus, was probably not begun until he returned to London; the laboratory for its manufacture will be mentioned below.

While at Oxford he appears to have performed all the usual experiments with sulphur, antimony, nitre, and vitriol, and it is on record that he received gifts of *Tinctura succini* and of *Sulphuris antimonii* from Mr. Denny (November 18, 1664). He injected various chemicals into the veins of animals, as for instance *sal ammoniac* (October 1667). Occasionally meteorological or astronomical events interrupted his other labours, as for instance when the barometer on March 19, 1665, reached the record height of $30\frac{5}{61}$ inches,[2] or when Wallis and Boyle, wanting to observe a conjunction, in

[1] Sulphur, salt, and mercury were the three principles of Albertus Magnus (1205–1280) and the Alchemists.

[2] Boyle at this time kept two barometers, one at Oxford and the other at Stanton St. John.

October 1664, were twice at the schools to take a view with the instruments of the observatory, but could not get in, the key having been lost or carried away. On February 21, 1667–8 they observed the New Star.

When the members of the Royal Society were once more able to foregather at Gresham College, several of them tried to induce Boyle to join them in London. For instance, on January 2, 1661, "Mr. Boyle was requested to bring in his cylinder, and to show at his best convenience the experiment of the air." On March 20 "Mr. B. was requested to remember his experiment of the air." On April 1 "he was desired to hasten his intended alteration of his air-pump." On May 15 "Mr. B. presented the Society with his engine." And the following passage in a letter from Sir R. Moray reveals the estimation in which they held him: "One thing I shall say for us all, if you did but wish us to be with you, as strongly as we wish you to be with us, I am somewhat disposed to be of the opinion you would draw Gresham College to Oxford" (October 7, 1661).

But, though frequently away, he did not finally leave Oxford until April 1668. On November 13, his devoted sister wrote:

"I have ordered Thomas to look out for charcoal, and should gladly receive your order to put my back-house in posture to be employed by you, against your coming, that you might lose no time after."—K. R.

The reference to charcoal is interesting because Boyle generally used a peat fire for distillations. He is believed to have been the inventor of the chemist's spirit-lamp. By 1671 he was settled in his new laboratory at the back of Lady Ranelagh's house in Pall Mall.

It would probably have been in his London laboratory that Boyle confirmed the observations of Brun and Hamerus Poppius that metals increase in weight when they are calcined. This fact was entirely unexpected, both because the calx formed appears to be a lighter substance than the metal from which it was formed, and also because in the case of the burning of wood there is always an apparent loss of weight.

Boyle experimented with copper, tin, iron, and lead.

The following quotations will give an idea of his methods.

"Into a very shallow crucible, we put an ounce of copper-plates, and set it in a cupelling furnace, where it was kept for two hours; and then being taken out, we weighed the copper, which had not been melted (having first blown off all the ashes), and found it had gained thirty grains."

A similar experiment with an ounce of copper filings gave an increase of 49 grains.

"Upon a good cupel, we put an ounce of English tin, of the better sort; and having placed it in the furnace, under a muffler, though it presently melted, yet it did not forsake its place, but remained upon the concave surface of the cupel, till, at the end of about two hours, it appeared to have been well calcined; and then being taken out, and weighed by itself, the ounce of metal was found to have gained no less than a dram."

"An ounce of lead was put upon a cupel, made of calcined hartshorn, and placed under a muffler, after the cupel was first made hot, and then weighed. This lead did not enter the cupel, but was turned into a kind of litharge on the top of it, and broke the cupel, whereby some part of the latter was lost in the furnace; yet the rest, together with the litharge, weighed seven grains more than the lead and heated cupel, when they were put in."

"Four drams of the filings of steel, being kept two hours on a cupel, under a muffler, acquired one dram, six grains and a quarter, increase of weight."

Yet, seeing that the dust of the furnace might have contributed to the gain in weight, he heated the metals in crucibles cemented together with clay and, in the case of tin, in glass flasks, the necks of which were stoppered, or sealed up. This method, as Dr. Lowry has pointed out, was of special interest as having provided the basis for Lavoisier's experiments more than a century later.

"To prevent all suspicion of any increase of weight, in the metals, arising from smoke, or saline particles, getting in at the mouth of the vessel, I made the experi-

ment in glasses, hermetically sealed, as follows. Eight ounces of good tin, carefully weighed, we hermetically sealed up in a new, small retort, with a long neck, by which it was held in the hand near a charcoal fire, that kept the metal in fusion; being now and then shaken for almost half an hour; in which time, it seemed to have acquired, on the surface, such a dark colour, as argued a beginning calcination; and it both emitted fumes that played up and down, and also, afforded two or three drops of liquor, in the neck of the retort. The glass was, at length, laid on quick coals, where the metal continued above a quarter of an hour longer in fusion; but, before the time was come, that I intended, to suffer it to cool, in order to its removal, it suddenly broke into a great multitude of pieces, and with a noise, like the report of a gun."

In order to reduce the risk of explosion the flask was next heated before sealing.

"Two ounces of filings of tin, were carefully weighed, and put into a little retort, whose neck was afterwards drawn slender to a very small apex: then the glass was placed on kindled coals, which drove out fumes at a small orifice of the neck, for a pretty while. Afterwards, the glass, being sealed at the apex, was kept in the fire for above two hours; and then being taken off, was broken at the same apex; whereupon I heard the external air rush in, because when the retort was sealed, the air within it, was highly rarefied. Then the body of the glass being broken, the tin was taken out, consisting of a lump, about which there appeared some grey calx, and some very small globules, which seemed to have been filings melted into that form. The whole weighed two ounces, and twelve grains." (*Works*, ii. 893–4.)

Jean Rey, *On an Enquiry into the Cause wherefore Tin and Lead increase in weight on Calcination*, 1630, had previously attributed this gain in weight to the condensation of air in the metal, thus:

$$Metal + Air = Calx$$

But Boyle, *New Experiments to make the Parts of Fire*

and Flame stable and ponderable, 1673, attributed the gain in weight to the absorption of ponderable heat, which was regarded as an element even as late as the time of Lavoisier. So that

$$\textit{Metal} + \textit{Heat} = \textit{Calx},$$

a result which, in the minds of the supporters of the "Phlogiston" theory, became

$$\textit{Metal} - \textit{Phlogiston} = \textit{Calx}$$

which calx then came to be regarded as a simple substance!

Meanwhile, Robert Hooke and John Mayow had been getting nearer to the truth.

"About 1680, some ten years later, Boyle fitted up another laboratory in Southampton Street, on the site now occupied by the Roman Catholic Church in Maiden Lane, Covent Garden. There his assistant, Ambrose Godfrey Hanckwitz, F.R.S. (1660–1741), prepared phosphorus from animal products by the method described in Boyle's posthumously published paper (*Phil. Trans.* 1693). For many years Hanckwitz was the only manufacturer of phosphorus in Europe. He claims to have been the first to obtain the element in a solid 'glacial' form (*phosphorus glacialis urinæ*). In the account which he gave of his method to the Royal Society (*Phil. Trans.* 1733) it is stated: 'An operator that is not well versed in the degrees of fire, and does not know how and when to take away these oils apart, will have nothing but a volatile salt and fetid oil, and get at least only a little unctuous opaque phosphorus; such as the famous Kunckel, Dr. Krafft, and Brandt did, as they acknowledge in their writings, but not our hard transparent phosphorus.'

"There is still extant an engraving of Robert Boyle's Laboratory in Southampton Street, which shows the furnaces and retorts used in the preparation of phosphorus. After Boyle's death this laboratory passed into the possession of Hanckwitz, and until the year 1862 was occupied by the well-known firm of operative chemists, Messrs. Godfrey and Cooke, who constantly used the original furnaces." [1]

[1] *Journ. Oxford Jun. Sci. Club*, 1892, p. 118.

Chemistry Classes

Boyle introduced into Oxford the first regular teacher of practical chemistry. Having heard from Hartlib that a chemist with a reputation for making excellent spirit of salt had expressed a resolution to come to England, he engaged him as his assistant in Oxford. This man was no less than "the noted chimist and Rosicrucian, PETER STHAEL of Strasburgh in Royal Prussia, a Lutheran, a great hater of women, and a very useful man" (Wood).

And it may be presumed that Sthael would have brought with him a supply of chemical apparatus including "those retorts in which spirit of salt is made and which cannot be had in England" (Hartlib's letter of April [1659 ?]).

1659.—PETER STHAEL began to take to him scholars in the house of John Cross, next on the west side of University College, sometimes known by the name of Deep Hall. He held two classes (= private collegia, Wallis).

First Class

JOSEPH WILLIAMSON, Queen's. Knighted and Secretary of State under Charles II.

Two others.

Second Class

Six persons, perhaps including:

WILLIAM LEVINZ, St. John's.

Mr. Sthael then "translated himself to house of Arthur Tylliard an apothecary, the next dore to that of John Cross, saving one (which is a taverne): where he continued teaching till the latter end of 1662."

Third Class

JOHN WALLIS, Professor of Geometry.

CHRISTOPHER WREN, All Souls. Knight and eminent virtuoso. Prof. of Astronomy.

THOMAS MILLINGTON, All Souls. Eminent physician and knight.

NATHANIEL CREW, Lincoln. Afterwards Bishop of Durham.

RALPH BATHURST, Trinity. Physician, President of Trinity, Dean of Wells.

HENRY YERBURY,[1] Magdalen.

THOMAS JEANES,[1] Magdalen,

RICHARD LOWER, Christ Church. Physician.

RICHARD GRIFFITH, Fellow of University. F. Coll. Phys.

FRANCIS TURNER, New College. Master of St. John's College, Cambridge.

BENJAMIN WOODROFF, Ch. Ch.

Several others, among whom was

JOHN LOCKE, Ch. Ch.

"A man of turbulent spirit, clamorous and never contented. The club wrote and took notes from the mouth of their master, who sat at the upper end of a table; but the said J. Lock scorned to do it; so that while every man besides of the club were writing, he would be prating and troublesome." However, a few years later we find him writing to Boyle, "I find my fingers still itch to be at it" (experiments in chemistry).

1663.—Mr. Sthael removed his school, or elaboratory. to a draper's house, called John Bowell, afterwards Mayor of the citie of Oxon, situat and being in the parish of All Saints, commonly called Allhallowes. He built his elaboratory in an old hall or refectory in the backside (for the house itself had been an antient hostle) of the Ram Inn, on the site of Nos. 113 and 114 High St., about two doors west of King Edward St.

WOOD, ANTHONY. Paid a fee of £3 for the course; 30*s*. at the beginning, 30*s*. at the end.

[1] Yerbury and Jeanes, both Doctors of Medicine, and both persons of independence of character, fell out over the question of the Fellowship allowed to M.D.'s at Magdalen (Bloxam, v. 177). They are both cited in a *Terræ Filius* speech (c. 1662) as instances of President Pierce's autocratic conduct. He is said to have cast Dr. Yerbury into purgatory because he would not kiss the feet of himself and his wife and to have expelled *virum ingeniosum* "T. Jeanes." (Macray, *Register*, iii. 188–9.)

Details of attendance:

May 1, Friday. At Mat Leeches with the chimicall club; paid to Kitt at the elaboratory 4*d.* and 2*d.* towards the next week.

May 4, Monday. At Mat Leches with Mr. (John) Curteyne and (Richard) Lower, 4*d.*; at the elaboratory, 4*d.*

May 15, Friday. To Kitt's father at the elaboratory, 4*d.*

May 18, Monday. For the making of *aurum fulminans*, 1*s.*

May 30, Saturday. To Mr. (Peter) Sthael for the conclusion of our class, 30*s.*; to Kitt's father for his dues, 1*s.*

Anthony Wood "got some knowledge and experience; but his mind still hung after antiquities and musick."

In 1664 Mr. Sthael, "for want of disciples, went to other places" and became operator to the Royal Society, continuing in that office till 1670, when he "return'd to Oxon in Nov. and had several classes successively, but the names of them I know not; and afterwards going to London againe, died there about 1675 and was buried in the church of S. Clement's Danes within the libertie of Westminster."

Some of Sthael's pupils retained their interest in practical chemistry and put their teaching to use. For instance, R. Sharrock of New College had prepared 'oleum salis' with Sthael, and found that it removed iron stains from linen. He appears from his letters to have been devoting this chemical knowledge to the concoction of medicines in 1667, though the medicines may not have been more complex than medical beers and scurvy-grass bread. He alludes to the *vesica* as the still continually employed by him in 1668.

Another pupil who developed unexpected enthusiasm was the inattentive John Locke. We will quote his own words:

"Christ Church,
"*February* 24, 1666.

"Honoured Sir,

"According to the direction you gave in your last letter to Mr. Thomas, I have endeavoured to provide paro-

nychia, and I think I shall be able to provide good store of it. The fittest time I suppose to gather it will be, when it begins to be in flower, which will be about a fortnight hence, the spring hereabouts not being over forward. How I shall dispose or order it for you, I must desire to be directed. Though by your approving of that way in other like cases, I have some thoughts to pound and seal up some part of it in a bolt head, and so keep it, since the juice being the thing desired; and not being fully acquainted with the way Helmont mentions he made use of to preserve juices, I know not how otherwise well to keep it. In the process of ${}_{0}{}^{0}{}_{0}$ ⊖ with V you did me the honour to send me, I must beg this additional favour, to know, whether in each distillation I must draw off the V of *ad siccitatem*; for I find, that if the fire be a little augmented, the volatile V being pretty well first gone over, the remaining liquor will rise in plentiful very white fumes; but I suspect this too violent way of proceeding. After having distilled it in this manner, I let it stand above twenty-four hours to cool; and though when I took off the head from the body, it had been several hours quite cold, and my nose were not within a foot of the body, yet there came out so quick and penetrating a steam, that it made me cry out, and made my eyes run over, but the effects of it quickly ended, and I was soon at ease again; though I dare be confident it is one of the briskest and most pungent steams in nature. Did I not know, how favourably you interpret any poor essays and slight observations of those, that are willing to learn, I should not venture to importune you with such trifles.

"Your etc.,

"JOHN LOCKE."

[V = quintessence].

The diaries of foreign travellers give us an occasional insight into the work and methods of those whom they happened to visit in Oxford. Borrichius, having noted that the Oxonienses are making much progress in chemistry, implies that two at least, Dr. Willis and Edmund Dickenson of Merton, had made discoveries which were still unpublished (1663).

"Dr. D. Willis dissolves iron in his principia by a light method, so that it imparts its strength immediately to the whole liquid, which experiment he also tried in my presence not unsuccessfully in water, for the water

immediately receives a strength not unlike that of acids; he maintained that the iron first dissolves by itself, even though there was no corrosive present. But that we might not think that Bilsius kept secrets to himself, Willis also kept this secret, nor did he bring himself to the point of revealing it to anyone, though no doubt attracted by the scent of the gain thence arising.

"D. D. Dichisohn takes strenuous exercise in that palæstra. He handed me some mineral salt to taste like sugar in sweetness, without any suspicion of Saturnine admixture, yet it does not seem difficult to conjecture the source whence it was derived. It is also known to him, as he tells, that the whole substance of water, but only after a long lapse of time, changes into earth like chalk."

Chemical Arts

Nor were the applications of the new science confined to members of the University, for at about the same time a curious discovery of some commercial value was attributed to an Oxford artisan.

In 1658 "William Byrd of Hallywell, in the suburbs of Oxford, stone-cutter, did find out the paynting or stayning of marble: a specimen of which he presented to the King after his restoration, as also to the Queen, and in 1669, to Cosmo Prince of Tuscany, when in Oxon." (Wood's *Life*; cf. *Phil. Trans*. No. 7.)

But Evelyn, in 1654, had already recorded that "that prodigious young scholar, Mr. Christopher Wren," had presented him with a piece of white marble, which he had stained with a lively red, very deep, as beautiful as if it had been natural.

A remarkable specimen of the art, exhibited in the Bodleian Library, where it was admired by Monconys in June 1663, was a black marble, in the middle of which was a lizard, formed so perfectly that it appeared to be petrified.

The following is an old receipt which was used for producing such effects. It is characteristic of the chemistry of the day:

"Take of aquafortis and aqua regia two ounces of

each; of sal ammoniac one ounce; of the best spirit of wine two drachms; as much gold as may be had for four shillings and sixpence; of pure silver two drachms. These materials being provided, let the silver, when calcined, be put into a vial; and having poured upon it the two ounces of aquafortis, let it evaporate, and you will have a water, yielding first a blue, and afterwards a black colour.

"Likewise put the gold, when calcined, into a vial, and having poured the aqua regia on it, set it by to evaporate; then pour the spirit of wine upon the sal ammoniac, leaving it also to evaporate; and you will have a golden coloured water, which will afford divers colours. And after this manner you may extract many tinctures of colours out of other metals.

"This done, you may, by means of these two waters, paint what picture you please upon white marble of the softer kind, renewing the figure every day for some time with some fresh super-added liquor; and you will find that the picture has penetrated the whole solidity of the stone, so that cutting it into as many parts as you will, it will always represent to you the same figure on both sides." (*Oxoniana*, iii, p. 56.)

Wren also invented a method of Etching on Copper. (*Hist. R. Soc.* ii.)

Salt-glazed Stone Ware

The mystery of salt-glazed stone ware was discovered by the ingenious John Dwight, B.C.L. (1661), of Christ Church, who set up a manufacture at Fulham, "which by methods and contrivances of his own, altogether unlike those used by the Germans, in three or four years time he hath brought to a greater perfection than it has attained where it hath been used for many ages, insomuch that the Company of Glass-sellers, London, (at least as early as 1676) who are the dealers for that commodity, have contracted with the inventor to buy only of his English manufacture and refuse the foreign.

"He hath discovered also the mystery of the Hessian wares, and makes vessels for retaining the penetrating Salts

and Spirits of the Chymists, more serviceable than were ever made in England, or imported from Germany itself.

"And hath found out ways to make an Earth white and transparent as Porcellane, and not distinguishable from it by the Eye, or by Experiments that have been purposely made to try wherein they disagree. To this Earth he hath added the colours that are usual in the colour'd China-ware, and divers others not seen before. The skill that hath been wanting to set up a manufacture of this transparent Earthen-ware in England, like that of China, is the glazing of the white Earth, which hath much puzzel'd the Projector, but now that difficulty also is in great measure overcome.

"He hath also caused to be modelled Statues or Figures of the said transparent Earth (a thing not done elsewhere, for China affords us only imperfect mouldings) which he hath diversified with great variety of colours, making them of the colours of iron, copper, brass, and party-colour'd, as some Achat-stones. The considerations that induced him to this attempt, were the duration of this hard burnt Earth much above brass, or marble, against all Air and Weather; and the softness of the matter to be modelled, which makes it capable of more curious work, than stones that are wrought with chisels, or metals that are cast. In short, he has so far advanced the Art Plastick, that 'tis dubious whether any man since Prometheus have excelled him, not excepting the famous Damophilus, and Gorgasus of Pliny.

"And these Arts he employs about materials of English growth, and not much applyed to other uses; for instance, He makes the stone bottles of a Clay in appearance like to Tobacco-pipe clay, which will not make Tobacco-pipes, though the Tobacco-pipe clay will make Bottles; so that, that which hath lain buryed and useless to the Owners, may become beneficial to them by reason of this manufacture, and many working hands get good livelyhoods; not to speak of the very considerable sums of English Coyn annually kept at home by it." (Plot, *Oxfordshire*, pp. 230–1.)

The peculiarity of salt-glazed stoneware is that the glaze is effected in the kiln itself, whereas other glazes are applied in a liquid or solid form to the body of the ware *before* firing. Towards the end of the firing, when the pieces have acquired a very high temperature, moist common salt is thrown into the oven. It is

volatilised, and, reacting with the water vapour present, is decomposed into hydrochloric acid gas which escapes, and into soda, which, attacking and combining with the silica of the clay in the body, forms with it a hard glass or glaze of silicate of soda, in which a little alumina is also always present.

When and where John Dwight first became acquainted with this use of salt is not known, but in 1671 he took out a patent for his process, and in the same year the first specimens of salt-glazed ware were being manufactured at Fulham. Soon after 1688 similar ware was being produced at Burslem by the Dutchman Elers, and in 1700 in Nottingham.

By a fortunate chance Dwight's own diary or notebook for 1698 was found a few years ago. It gives a number of interesting personal details. He appears to have been in the habit of hoarding considerable sums of money in his furnace (!). "460 guineas in a pair of covered stone gorges concealed in two holes under the fireplace on both sides of the furnace in the 'old Labouratory'; 240 guineas in a wooden box under the fireplace in the garret; and two boxes full of milled money 'in two holes of that great furnace running in almost to the oven.' The boxes, he tells us, may be drawn out with a long crooked iron standing behind the kitchen door"[1]

Use of Nitrates in Agriculture

To this period belongs one of the fundamental discoveries in scientific agriculture. For it was now recognised that 'nitre' was in some way beneficial to the growth of plants. Sir Kenelm Digby and John Mayow both experimented on the Sal-Nitro; and in 1675 Evelyn wrote, "I firmly believe that where salt-petre can be obtained in plenty, we should not need to find other composts to ameliorate the ground."

Glass Manufacture

(See p. 42)

[1] A. H. Church, *Some Minor Arts as Practised in England*, 1894.

III

THE RESTORATION, AND THE TEMPORARY DECLINE OF SCIENCE IN OXFORD

Before the "wonderful pacifick year 1660" had drawn to a close several of the most active members of the "experimentall philosophicall clubbe," finding tranquillity restored, returned to London. Their departure was an irreparable loss to Oxford, for with them went the spirit of scientific enquiry, that seeking after knowledge at first-hand, which is so common in childhood, but which, as modern experience has often shown, is so easily destroyed by over-education. The weekly gatherings at Gresham College in the city were resumed and resulted in the Incorporation of the Royal Society (1663).

The temporary presence in Oxford of the corner-stones of the Philosophical College, as Boyle would have called them, had a beneficial reaction on the University; witness a passage in Beal's letter written eleven years after the Restoration :

"At my request a young Oxonian prepared me a list of fit, capable, and hopeful persons, addicted to the design of the Royal Society and willing to entertain correspondences, and to assist in them. They seemed to me to be by their qualifications, and number, very considerable ; some in every college, and in every hall. Only in one college there was but one named. . . . There are excellent professors, some lecturers, and very many students of useful arts among them. And in time they may have their meetings in some of their publick schools, after fit lectures ; and the wings of the Stub-

bians [1] are already broken, and their reputation withers, as Dr. Bathurst told me." (J. Beal, *Letter* to Boyle, November 27, 1671.)

But there were also men of another stamp, which is well illustrated by Tom Whittal, a student of Christ Church, "who would needs maintain, that if a hole could dexterously be bored through the skull to the brain, in the midst of the forehead, a man might both see and hear and smell without the use of any other organs" (Letter of S. Evelyn, August 1668). We have known many such among men who are said to have had a good classical education.

And then there were the "Stubbians."

The greatest of the 'fit, capable, and hopeful persons,' left in Oxford, was without doubt, JOHN MAYOW, who as a Fellow of All Souls, had taken a B.C.L. degree in 1665 at the age of twenty-two years. He studied anatomy with Lower, Willis's chief assistant, but we do not know where he made his chemical experiments. In 1668 he published the *Tractatus de Respiratione*, in which he showed that air was a mixture of two kinds of gases, the one, *spiritus nitro-aereus*, necessary both for combustion and for respiration, and the other incapable of supporting combustion and respiration, which was left after the removal of the *spiritus*. This, the practical discovery of oxygen, was still further elaborated in 1674, in the epoch-making *Tractatus Quinque Medico-physici*, the first treatise of which was *De sal-nitro et spiritu nitro-aereo*.

He proved that this *spiritus* was contained in saltpetre, and argued that the corrosive action of nitrous acid and of the explosive nature of gunpowder were due to its presence. By heating antimony in an enclosed volume of air in the sun's rays focussed upon it by a lens, he noticed that the antimony became a calx, increased in weight and that the volume of the air

[1] Henry Stubbe of Christ Church, the author of an *Essay on the Good Old Times*, had violently attacked the Royal Society, which was defended by Glanvill, the Rector of Bath. Glanvill had the last word in the controversy, for fate ordained that he should preach the funeral sermon after Stubbe had been accidentally drowned near his parish.

lessened. "Can we," says he, "conceive whence that increase of weight is derived, except from the fixation of something in the air?" The calx of antimony left after the heating also appeared to be identical with that obtained by heating the metal with nitric acid. Sulphuric acid might be obtained indifferently by burning sulphur in air or boiling with aqua fortis, and must therefore contain something common to both media. Iron pyrites also would absorb the *spiritus nitro-aereus* on exposure, for the green vitriol which resulted yielded sulphuric acid on distillation. In short, Mayow had grasped the essential facts about the formation of acids and oxides, and had thus anticipated the work of Lavoisier (1775) by more than a century.

But Mayow left Oxford in 1675, settled in Bath as a practising physician, close to the waters of which he had already examined the saline constituents (cf. chapter xv of the *De sal-nitro*). He was elected F.R.S. in November 1678; and a few months later, on a visit to London, died "in an apothecarie's house bearing the sign of the Anker in York Street, Covent Garden, having a little before been married not altogether to his content."

Thus closed the brief life of the greatest chemist whom Oxford has ever produced. His works, a century in advance of the times, were unappreciated during his life and were soon neglected, buried and forgotten under a thick pall woven in Germany by Stahl, out of a warp of genuine facts and a weft of false hypothesis.

The false hypothesis was the assumption of phlogiston; the resultant fabric was so cunningly woven that a generation of chemists (including such men as Cavendish and Black, Priestley, Scheele, and Bergman) failed to notice the many glaring contradictions in its meshes between the actual facts and the phlogistic doctrine. Had they been able to emancipate their mental vision from the speciously simple explanation of Stahl, and had studied the *Tractatus* of Mayow with an open mind, the chemistry of the eighteenth century would have proceeded on a higher plane.

Not till fifteen years *after* Lavoisier's discovery of oxygen, was any recognition paid to the merits of

Mayow. Dr. Beddoes, and later Mr. Yeats, then gave detailed accounts of the work of the unrecognised genius, lauding him even to the extent of placing him upon the same pedestal as Newton, who, it may be remarked, appears to have wholly ignored Mayow's work. But then, it must also be remembered that the first accounts that appeared of Mayow's work were abstracts printed in the *Philosophical Transactions*, which grossly misrepresented his views and misstated his discoveries.

The questions of more immediate interest for our present purpose are, Where did he work, and what were the means at his disposal ?

Yeats represented him as " retired from the world." " He planned and executed in the cloisters of a college experiments the most elegant and decisive that the greatest genius could contrive. Unassisted by the labours of others, not encouraged by the adoption of his opinions, his aspiring genius soared into the regions of truth amid the obstacles of surrounding opposition."

Had he worked in Boyle's laboratory we may take it for granted that the light of his discoveries would not have remained hidden. He must have done his work within All Souls College. Moreover, it would not appear that he was acquainted with Boyle's work before it was published, since he distinctly states that part of his treatise on sal nitrum was written before the published account of Boyle's experiments came into his hands ; but he certainly made use of Boyle's air-pump.

No chemist before Mayow appears to have collected gases in flasks or vessels inverted over water, and to have studied change of volume in the gas by observing the rise or fall of water in the glass vessel. His predecessors had, it is true, collected the products of condensation of vapours passed into cold receivers, but Mayow will always be regarded as the father of pneumatic chemistry.

His methods and apparatus were thought up-to-date at the end of the eighteenth century. Dr. Beddoes, in a letter to Dr. Goodwyn, dated February 12, 1790, wrote ' at sight of the annexed representation of Mayow's

pneumatic apparatus' a certain sedate northern professor to whom both Drs. Beddoes and Goodwyn may have obligations 'lifted up his hands in complete astonishment.'

His work in physiology will be noticed in another place.

With apparatus shown in the figure Mayow showed

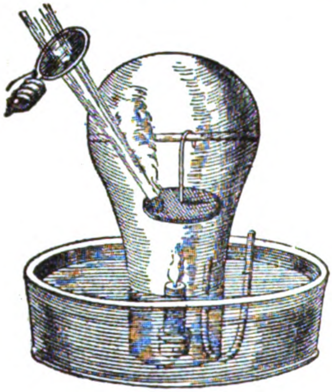


Fig. 4.

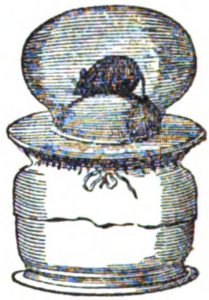


Fig. 5.

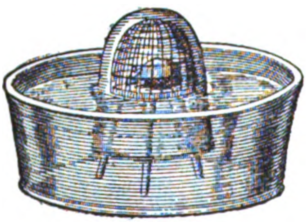


Fig. 6.

Fig. 7.

THE APPARATUS OF MAYOW.

(From Lowry's *Historical Introduction to Chemistry*, after Mayow, 1674.)

that a given volume of air decreases when a candle or piece of camphor is burnt in it (fig. 4), and that the same effect may be demonstrated when a mouse breathes air, either by the in-sucking of a stretched bladder (fig. 5), or by the rise of water under a bell jar (fig. 6). By means of another apparatus (fig. 7) he collected the gases prepared by the action of acids on iron.

It will be noticed that Mayow collected his gases over the acid used to prepare them. He made no

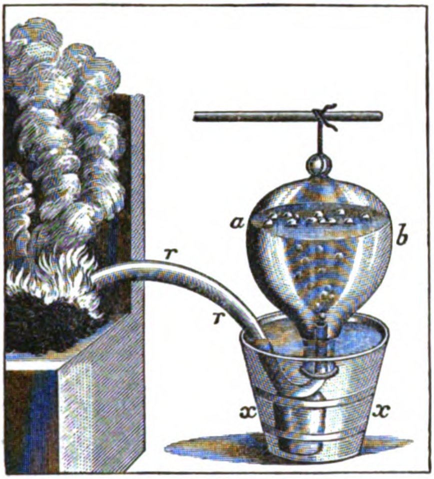


FIG. 8.—HALES' IMPROVED APPARATUS.
(From Lowry, after Hales, 1727.)
The Receiver *ab* is separated from the Generator, an iron retort *rr*.

attempt to separate the generator from the receiver of the gas.

It was left to Stephen Hales, the physiologist of Benet (now Corpus Christi) College, Cambridge, to

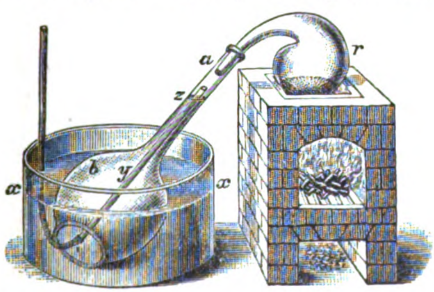


FIG. 9.—HALES' APPARATUS FOR MEASURING GASES.
(From Lowry, after Hales, 1727.)

The gas generated by heating vegetable or animal substances in the glass retort, *r*, is passed into the gauge, *ab*, standing in a trough of water, *xx*. By a syphon-tube, *y*, air could be drawn out and water sucked up as far as *z*. The fall of the level, *xx*, of the water, after heating the contents of the retort, showed how much gas had been liberated.

invent the modern method of collecting gases in an inverted receiver standing over water in a pneumatic trough. (*Vegetable Statics*, 1727.)

Another great achievement of Mayow's was to infer that although in salts, acids and alkalis 'pass into a neutral substance, yet they do not, as is generally supposed, entirely destroy each other.' He even distinguished between the relative strengths of acids and alkalis. He noted that volatile alkali can be displaced by fixed alkali and that volatile acid (nitric acid) is 'expelled from the society of the [alkali] by the more fixed vitriolic acid.' He thus showed the binary composition of salts and stated the facts which led to the grouping of salts in three classes, viz. those prepared from (1) metals, (2) alkalis, and (3) earths.

With the exception of the air-pump, Mayow's experimental outfit was of the simplest. He refers to crucibles, to glasses, in which he heated substances with a burning-glass, and to a tubulated retort. He used cupping glasses and a small glass tube of the diameter of a goose-quill, and about four inches long and sealed hermetically at one end. He knew how to draw glass threads fine enough to be wound round a bobbin or tied in a knot, he could make glass globules with a sharp beak attached to them, commonly called glass drops, which are formed by dropping a little molten glass into cold water (= Prince Rupert's drops).

Other Chemical Laboratories

Chemical laboratories were few and far between in the seventeenth century; materials and apparatus were both scarce and costly; experimenters were frequently tricked by quack vendors into buying unnecessary and expensive apparatus. Thus antimony cups[1] were sold by one Evans

[1] An antimony cup belonging to Dr. Sam Seabury of Duxbury, U.S.A., was valued at 5*s*. in 1680 (Baas, *History*). Wine, allowed to stand in such a cup, forms tartar emetic and was taken as a medicine. There is such a vessel in the South Kensington Museum (No. 1370, 1910) which looks like a small pewter mortar, in an original leather case, with an outer box of straw-work, that looks like North American Indian work on birch bark. It is stated to have belonged to Lord Peterborough in the seventeenth century, and is accompanied by a letter of precise directions for its use.

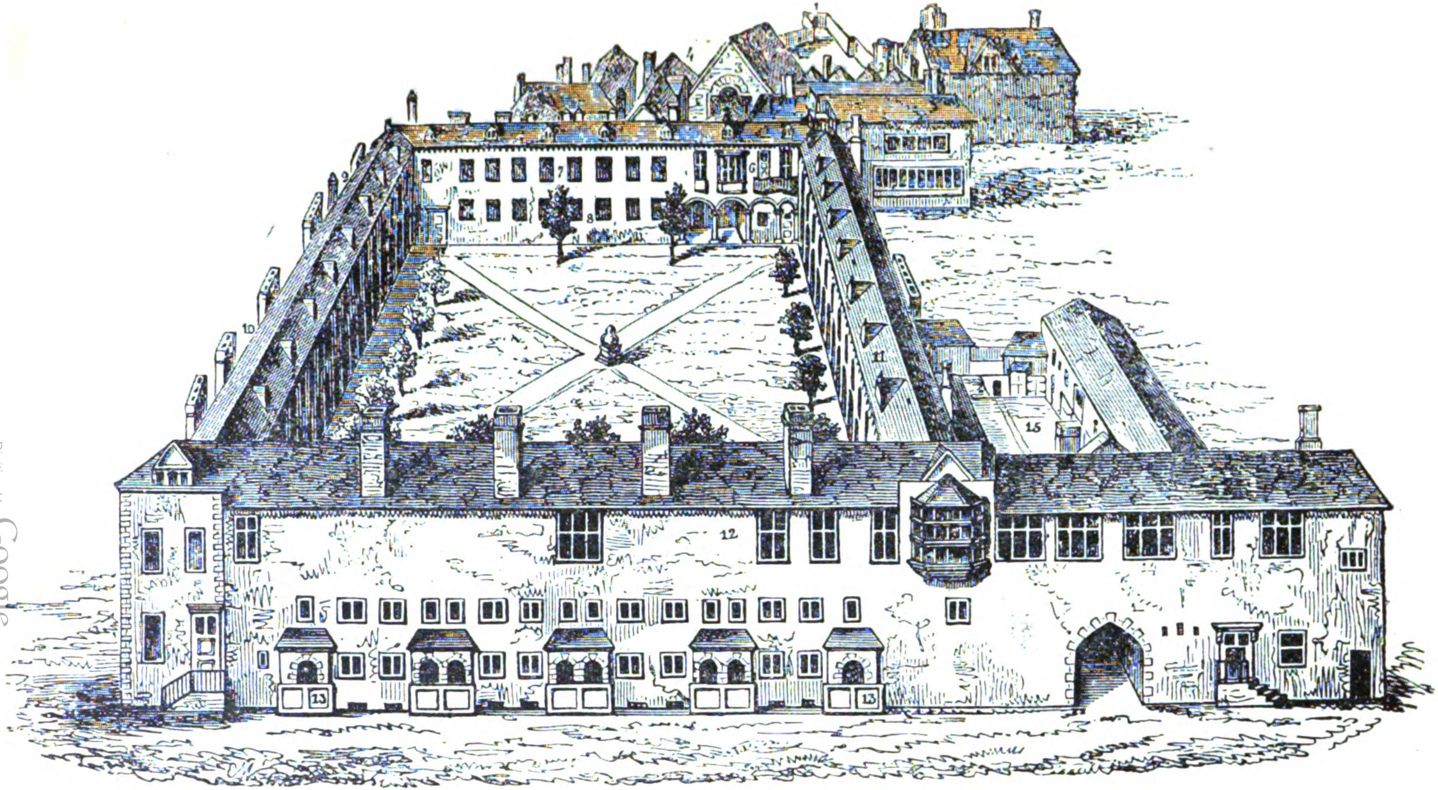


FIG. 10.—GRESHAM COLLEGE.

10. Astronomy Professor's Lodgings. 7. Divinity Professor's Lodgings. 5. Observatory. 8. Physic Professor's Laboratory. 6. Geometry Professor's Lodgings.

of Fetter Lane at 40*s*. apiece, before 1649, which being probably cast in ordinary regulus of antimony would not have been worth more than 10*s*. each (Hartlib, July 24, 1649).

To remove some of these obstacles from the paths of students, a general chemical council was constituted and sat frequently, not far from Charing Cross. It was even proposed to establish a universal Laboratory, to the cost of which Sir Kenelm Digby [1] was to contribute £600–£700 (Hartlib, May 8, 1654).

This remarkable man had been so upset by the death of his wife in 1633 that he retired to Gresham College, and there "diverted himself with chymistry and the professor's good conversation" in a "fair and large laboratory . . . erected under the lodgings of the Divinity Reader." He "wore a long mourning cloake, a high crowned hat, his beard unshorne . . . as signes of sorrowe for his beloved wife," who, as gossip reported, was shown to have had but little brain at a post-mortem examination, which was attributed to the fact that she had drunk viper-wine for her complexion—by her husband's advice. Digby employed an Hungarian operator of the name of Hans Hunneades.

His imprisonment in Winchester House, Southwark, resulted in a pamphlet on glass-making. From 1644 to 1653 he was in Paris, where he attended Le Fevre's chemical lectures (Evelyn, *Diary*). After the restoration of Charles II he lived "in the last faire house westward in the North portico of Covent Garden. . . . He had a laboratory there" (Aubrey), and there during the last years of his life (*c*. 1661–5) he worked, talked, and entertained. His house became a kind of academy where wits, experimentalists, occultists,

[1] Sir Kenelm Digby, *b*. July 11, 1603, *d*. 1665, the great benefactor to the Bodleian Library, had been partly educated by Laud and then by Thomas Allen, mathematician and occultist of Gloucester Hall, who, as a mark of his profound admiration for Digby, left him his library rich in early scientific MSS.

At the age of seventeen he set off on the Grand Tour.

He corresponded with the Rev. Mr. Sandy (— Richard Napier) of Great Lindford, who superintended his studies, which included *Phyzick* and *Chirurgery*—on which his notes were published by Hartman, his steward, after his death.

"Sandy" was so pious that his "knees were horny with frequent praying," while he studied alchemy, astrology, and was a friend of Dee, Lilly, and Booker, and had a large medical practice in the Midlands.

In Florence young Digby met the Carmelite friar who brought from the East the secret of the Powder of Sympathy, which cured wounds without contact.

philosophers, and men of letters worked and talked. Monconys, who visited the laboratory in June 1663, recorded in his journal that Digby's artist was one of the most honest men in his profession, "he confessed that he had learnt nothing in his whole life-time, which he had devoted to chemistry, except that he knew nothing of it."

In the same year Digby became a member of the Council of the Royal Society.

We know of the following private laboratories in or near London.

JOHN DEE "kept a great many stilles goeing" at his laboratory in Mortlake, west of the house where the tapestry hangings were made. He died in 1672. (Aubrey, *Lives.*)

Dr. CLODIUS HARTLIB'S very chemical son-in-law, had a laboratory, ? in Axe Yard, with "8 furnaces finished, but 5 more must be added" (Hartlib, September 14, 1658).

Another laboratory, that of NICOLAS LE FEVRE, was famous for its Cabinet of Drugs, which had belonged to the wife of Cromwell, and contained more than eighty drawers.

"*November* 17, 1651.—To see Monsieur Febur's[1] course of chymistry [at the Jardin du Roi in Paris], where I found Sir Kenelm Digby ['an arrant mountebank'], and divers curious persons of learning and quality. It was his first opening the course and preliminaries, in order to operations."[2]

Several of the apothecaries seem to have had the standing of manufacturing chemists.

"*September* 1, 1663.

". . . Mr. BUTTERSBY at the great Helmet in Fenchurch Street, who does provide our medicaments for us, and is a very honest and able apothecary. . . .

"I desire your advice about fixing of arsenic a ready cheap way. One Smart, that dwells in Dorchester House, a drudging operator, made me pay ten pence for an ounce,

[1] Nicasius or Nicolas Le Fevre, or Lefebure (*d.* 1669), was demonstrator of chemistry at the Jardin du Roi at Paris when Evelyn attended his course in February 1647. In 1660 he was appointed Professor of Chemistry to Charles II, and apothecary in ordinary to the royal household. Charles entrusted him with the management of the Laboratory at St. James's Palace (*c.* 1664–6). His *Traité de la Chymie* passed through several editions and translations (*D.N.B.*). It was translated into English by a gentleman of the Privy Chamber, P.D.C., and therefore presumably at the King's suggestion, in 1670. It was called *A Compleat Body of Chemistry.*

[2] Evelyn, *Diary.* Evelyn had already attended Lefebure's course in Paris in 1647.

but it was well fixed, and may be given inwardly, in a dose of 3, 4, or 5 grains, and decocted loses no weight, but imparts a balsamic virtue. . . . That operator Smart at Dorchester House sold me a stinking sulphurous balsam, that I have used with miraculous success in sore eyes. I forget what he calls it; Mr. Buttersby can help you to it. He makes sulphur martis." (S. Collins, *Letter* to Boyle.)

JONATHAN GODDARD, *d.* 1675, matric. Magdalen Hall 1632, Warden of Merton College, Physician to Oliver Cromwell, F.R.S., had a laboratory for chemistry at Gresham College, where his stills were looked after by a Mr. Mich. Weekes. He was a zealous member for the improvement of natural knowledge amongst the Fellows of the Royal Society, who "made him their drudge, for when any curious experiment was to be donne they would lay the taske on him" (Aubrey, *Lives*).

Various communications by him, from 1660 onwards, are entered in the register of the Royal Society. No one better knew the value of a laboratory to a medical man, for the compounding of his own arcana, or secret remedies. The chief of these was 'Goddard's drops,' or 'guttæ Anglicanæ,' a preparation of spirit of hartshorn (ammonia) with a few irrelevancies added, such as skull of a person hanged, dried viper, and the like. Goddard was currently believed to have communicated the secret of the drops to Charles II for a consideration of £5,000: an alternative story is told below. A collection of the 'arcana Goddardiana' was published as an appendix to the second edition of Bates' *Pharmacopœia* (1691). To him is also attributed a proposal of supposed great economic value, namely, to make wine from the sugar-cane, and incidentally to give a fillip to the languishing prosperity of the British plantations in Barbados. His 'Experiments of Refining Gold with Antimony' were published posthumously in the *Philosophical Transactions*, xii. 953 (*D.N.B.*).

The laboratory and traditions of DREBBELL, the inventor of a thermometer and of bodied scarlet, who died in London in 1634, were probably carried on by his son-in-law, Dr. KEFFLER, or KUFFLER, commended by Hartlib's son as a 'very inventive wit.' "He doth now make exactly the stopples of glass to stop bottles withal instead of corks, which I suppose may prove a very special kind of accommodation for preserving of wine, ale, and all other kind of

CHARLES II.
By Sir P. Lely

liquors" (Hartlib, *Letter*, May 25, 1685). In 1666 Evelyn reports him as using iron ovens (*Diary*, August 1, 1666).

When the plague was at its height Dr. Wilkins, Sir W. Petty, and their assistant, Mr. Hooke, retired to Durdans, where Evelyn found them "contriving chariots, new rigging for ships, a wheel for one to run races in, and other mechanical inventions; perhaps three such persons together were not to be found elsewhere in Europe for parts, and ingenuity" (Evelyn, *Diary*.)

At Gresham College the officials were soon after proposing to undertake "several good things, as the collecting a repository, the setting up a chemical laboratory, a mechanical operatory, an astronomical observatory, and an optick chamber," in March 1665–6; but their scheme was stopped by the Great Fire.

In another laboratory in the city GEORGE WILSON, the transmutationist, was keeping his furnace fires alight for months, no doubt "by an abundant phlebotomy of the purse," but had no luck in his results. The 'mercurial water' he made with Mr. T. T. in August 1661, was lost in the Great Fire. His 'Chrystal Egg,' assiduously incubated from June 14 to July 19, 1677, burst in his Athanor, and in December 1688 the mob broke up his apparatus. In October 1677 he bought 5 lbs. of mercury from Mr. WILLMORE, the refiner, and heated it until March 4, 1678–9. The third edition of his *Compleat Course of Chymistry* appeared in 1709.

King CHARLES II, in spite of his derision of the Royal Society for their experiments on air,[1] had also a liking for chemistry.

The entertaining author of the *Gold Headed Cane* relates that His Majesty bought the receipt of the *arcanum Goddardianum* for £1,500, and was wont to witness the distillation as it was going on. The drops were procured from raw silk, one pound of which yielded an incredible quantity

[1] At a meeting of the Society King Charles, on Wren's proposal, was entertained with some experiments upon the barometer, which, "besides being amusing, were useful and easy of exhibition."

"Their learned speculations
And all their constant occupations
To measure and to weigh the air
And turn a circle to a square."
Butler, *The Elephant in the Moon.*

of volatile salt, and in proportion the finest spirit that ever was tasted. The salt (a coarse kind of spirit of hartshorn) being refined with any well-scented chemical oil, made the King's Salt, as it was used to be called.

"The King's little elaboratory was situated [in White Hall], under his closet, a pretty place"; and there on January 15, 1669, Pepys and Lord Brouncker, under the guidance of Sir R. Moray, saw "a great many chymical glasses and things," but understood none of them. His Majesty was moreover reported to have been engaged in experiments for the production of mercury within a month of his death (Wheatley).

PRINCE RUPERT (1619–82), the reputed inventor of "chemical glasses which break all to dust by breaking off a little small end" (which was a great mystery to Pepys, *Diary*, January 13, 1662), continued his chemical researches during the last ten years of his life in his house in Spring Gardens (1672–82). He proposed a new method of making gunpowder, and carried out Ludwig von Siegen's process for making mezzotints.

In 1692 Dr. EDMUND DICKINSON of Merton had settled as a physician in Westminster. He had always been a keen student of alchemy, and even in his infirm old age, when he was visited by Evelyn in his retirement, he was 'yet continuing chymistry' (*Diary*, June 1705).

Glass Manufacture

In London flint glass was manufactured at the Savoy and Crutched Friars in 1557; and in 1567 Jean Quarre, of Flanders, established works there. About 1670 glass was being made in Oxfordshire, at Henley, by Bishop under the patent of his predecessor, Ravenscroft. The method, stated to have been introduced by a Signor de Costa of Montferrat, was investigated by an Oxford chemist, Dr. JOHN LUDWELL, M.D., Fellow of Wadham College, who found that the mixture used was in the proportion of 1 lb. of black flints calcined, and a white crystalline sand with 2 oz. of nitre, tartar and borax.[1] Ludwell appears to have been one of the first to realise that glass is a kind of *solution*. He seems to have been commercially minded, for in a speech by a *terræ filius*, it is suggested that he was making money as a mercer, and he was addressed as "alderman." He died in 1723, and was buried in the chancel of the University Church, under a diamond-shaped stone with his name.

[1] Plot, *Oxfordshire*, p. 253.

IV

THE FIRST UNIVERSITY CHEMICAL LABORATORY

Elias Ashmole, 1683

Our first scientific laboratories had but an ephemeral existence. They sprang into being when the range of the experiments no longer admitted of work in an ordinary living-room. Not that the early pioneers of science were fastidious, if we judge them by George Bathurst, B.D., who kept a hen in his chamber at Trinity to hatch eggs which with Harvey he opened daily to see the progress and way of generation.

But soon a subsidiary influence gave support to the study of Natural and Experimental Philosophy in Oxford. The brilliant success of the Fellows of the Royal Society in opening up new pathways in science, the wonders of nature they were revealing, and the practical bearing of some of their discoveries had aroused much attention everywhere, and not least at the gay and frivolous Court of Charles II. The promotion of natural studies became a fashion; and the foible of a courtier was the indirect means of providing Oxford with the first University Chemical Laboratory.[1]

The Windsor Herald, Elias Ashmole, at once astrologer, alchemist, virtuoso, and curioso, had amassed a raree-show of a miscellaneous character. Partly from a wish to find a permanent home for his collections, and partly to pose as a great founder, he conceived a plan

[1] By a curious coincidence, the three first chemical laboratories for instruction were all founded in the same year. The Ashmolean Laboratory, the Laboratory of J. M. Hofmann in Altorf, and Charles XI's Laboratory at Stockholm were all opened for public instruction in 1683.

of making his collections the nucleus of a Gresham College and Royal Society in Oxford. Unfortunately for the permanence of his scheme, his ambitions were greater than his means for carrying them out, and the initial ardour of the University began to cool soon after the inaugural banquet had been consumed, with the result that, of Ashmole's Scientific Institution, little now remains but the name. Still, for a century and a half it was the home of the physical sciences in Oxford.

Ashmole's scheme for a scientific institution, or museum, comprised a laboratory, a repository for his collections of natural objects, books and manuscripts for study, and a lecturer who should discourse to students upon the contents and show them to visitors. That Oxford could boast a thoroughly eligible candidate for so congenial a post is clear from the following letter:

"The Bearer hereof will neede no recomendation from me, when you shall understand that it is Dr. Plott, the learned Author of the *Natural Historie of Oxfordshire*: It is upon the reputation of your own worth, as well as yr magnificent gift intended to the Universitie, that he has the ambition to be better known to you: They are (I heare) designing to erect a Philosophical Lecture upon Natural things, and their inclination to pitch upon this knowing gentleman for that purpose (whose talent and merits are so eminent) I am sure, cannot misse of your concurrent suffrage.

"Sir,

"Your most humble and obedient servant,

"J. EVELYN."

"WHITEHALL,
"*December* 7, '77.

The result of Plot's visit is recorded in Ashmole's diary for December 10: "I told him if the University liked of him, he should have my suffrage."

MUSEUM ASHMOLEANUM, SCHOLA NATURALIS HISTORIÆ, OFFICINA CHYMICA

It was not until March 1683 that the building to house the collections was finished, at considerable cost to the University. It consisted of three storeys, of

which the upper was devoted to the Museum Ashmoleanum, the middle served as a School of Natural History, and the lowest a cellar, as the Laboratory and store-room.

Now that Ashmole's name is being almost exclusively associated with the archæological collections of the University, it is well to remember that this limitation was not the intention of the founder. He was at one with the University in desiring to advance natural science, chemistry especially, and the name Ashmolean would be more appropriately applied to the scientific collections in the New Museum in the Parks, to which several of his natural history specimens were transferred, than to the archæological collections in Beaumont Street.

The initial cost of fitting up the cellar as a chemical laboratory was defrayed by the University, bills amounting to at least £225 being paid in 1683.[1]

	£	s.	d.
To Wood yᵉ Stonecutter for work done at the Laboratory	106	17	4
To Thomas Robinson yᵉ mason for work done there siml^{r}	31	2	4
To Job Dew Plaisterer for work done there . . .	1	16	0
To William Longe & John White Carpenters, siml^{r} .	23	14	7
Payd to Dr. Plott what he has laid out for some vessels etc. for the Laboratory	17	9	0
To Chr. White for Tin Copper & Iron Vessels siml^{r} .	44	17	0

Although not quite finished, the laboratory was used for experiments before the middle of 1683.

On Monday, May 21, the Duke of York, his Duchess, and her daughter the Lady Anne, visited Ashmole's Museum, " where after they had heard an English speech spoken by Dr. Plot, the curator, in the second upper room, they were entertained first with the rarities in the upper room, and afterwards with a sumptuous banquet there (it cost 50 li or 60 li) at the charge of the Universitie. Then they went down to the elaboratory, where the[y] saw some experiments to their great satisfaction." (Wood.)

There, ' down a descent by a double pair of staires '

[1] A last straw on the back of the University ! " The building of the Elaboratory did so exhaust the University mony, that no books were bought in severall years after it." Hyde in a letter to Wake, printed by Macray, *Annals of the Bodleian.*

was the first University Laboratory, "perchance one of the most beautiful and useful in the world, furnished with all sorts of furnaces and all other necessary materials in order to use and practice, which part is with very great satisfaction performed by Mr. CHRISTOPHER WHITE,[1] the skilful and industrious operator of the University, who, by the direction of the Professor (Plot), shows all sorts of experiments chiefly relating to that course, according to the limitation established by the order of the Vice-Chancellor.

"Near adjoining are two fair rooms, whereof one is designed for a *chymical librarie*, to which several books of that argument have been already presented. The other is made use of as a store-room for Chymical preparations, where such as stand in need of them, are furnished at easy rates, the designe of this building being not onlie to advance the studies of true and real philosophy but also to conduce to the uses of life and the improvement of medicine." (Wood.)

At that time powerful furnaces were the most important item in the equipment of a well-appointed laboratory. The worker in a modern laboratory who can at any moment obtain a great heat for his chemical operations with no more expenditure of time and energy than is involved in the turning of a gas-tap and the striking of a match, would not find it easy to carry on his labours under the conditions that obtained in those early days when the sole source of heat was solid fuel. The proper construction and convenient disposition of his furnaces were the chief concern of every practical chemist.

The Ashmolean Laboratory, like the other seventeenth-century laboratories of the College of Physicians in Warwick Lane, and of the University of Utrecht (1698), was built under a masonry vault for the sake

[1] WHITE was known as the 'University Chemist.' Wood's description of his duty on the occasion of the reception of King James on September 1687 may amuse his successors. "Mr. Piers, superior bedell of arts, being fat and weildy, could not ride or walk as the others could, whereupon he, with leave of the Vice-Chancellor, deputed Christopher White, the Universitie Chymist, to ride and walke for him, which he did."

of safety from fire. The furnaces were arranged against one wall, under hoods, a plan which was also adopted in the laboratories of Pepys, Barchusen, and Thenard, as distinguished from the laboratories of Dr. Higgins, and the Society of Apothecaries in which the furnaces were clustered around a central chimney-stack to which the several flues converged.

The greater convenience and entire sufficiency of smaller and portable furnaces does not appear to have been generally realised until the eighteenth century, when most chemists, including Dr. Black of Edinburgh, found that almost all ordinary operations could be conducted with simple portable furnaces of various types.

The Philosophical Society of Oxford

In the middle of September 1683 when the elaboratorie was quite finisht certaine scholars went a course of chimistrie, viz.:

Dr. R. Plot.
Mr. John Massey, of Mert. Coll.
Stephen Hunt, of Trinity, proproctor.
(William) Smith, M.A., Univ. Coll.
(Nathaniel) Boys, M.A., Univ. Coll.
Charls Harrys, a laick.

These had meetings in the large room over the elaboratory every Friday in the afternoone to talke of Chymicall matters, and were framed into a solemn meeting on Friday October 26.

Their discourses were registered down by Dr. Plot. The persons that met were:

Dr. John Wallis, the cheife.
Dr. Ralph Bathurst, Trinity.
Dr. Henry Beeston, Warden of New College.
Dr. Henry Aldrich, Ch. Ch.
Dr. R(obert) Plot.
Dr. R(obert) Pitt, M.D., Wadham.
Dr. William Gibbon, M.D., St. John's.
Dr. Thomas Smith, Magdalen.

Edward Bernard, Professor of Astronomy.
Josiah Pulleyn, Magdalen Hall.
John Massey.
Stephen Hunt, Trinity.
Nathaniel Boys, University.
William Smith, University.
Thomas Pigot, Wadham.
William Musgrave, Fellow of New Coll., LL.B., Student of Physic, Secr. of Royal Society, 1694.
John Ballard, Fellow of New Coll. M.A., LL.B.
Charles Harrys, lay-man.
William Gould, Fellow of Wadham, Bac.Phys.
Samuel Desmasters, Fellow of Oriel, Bac.Phys.
November 28, (Friday).
John Caswell, Vice-President of Hart Hall.
Michael Evans, Ch. Ch.

In December following was such a 'conventus' set up at Dublin by the meanes of Dr. Robert Huntingdon, provost of Trin. Coll.; seconded by Dr. Charls Willoughby, who is the chairman: Dr. (Narcissus) Marsh, bishop of Fernes: William Molyneaux. And Dr. Huntingdon sent a letter of the products of the first meeting to Dr. Plot about the middle of Dec. wherein Mr. Molineux spoke most.

Thus arose "The Philosophical Societie" of Oxford for the improvement of real and experimental philosophy. "In order to the better carrying on this generous and usefull designe they have setled a correspondence with the Royall Societie at London (of which severall of them are fellowes) and with the society at Dublin in Ireland lately established there for the same good purpose."

A code of thirteen rules was drawn up at a Meeting on March 4, 1683–4, two other rules being added later. They were written out in the minute book (MS. Ashm. 1810, p. 24), and are subscribed by fourteen of the original members whose signatures fill the middle column, and by the subsequently elected members whose signatures fill the side columns, and to which we have appended colleges and dates of election.

LIST OF SIGNATORIES

Alex. Pudsey
(Magd. 12 Aug. 84)
Caspar Marcke
(of Brandenburg,
7 Oct. 84)
James Anderton
(of Boxford, Berks,
7 Oct. 84)
John Cooke
(of near Newbery,
27 May 84)
Anth. Farmer
(Magd. Hall, 14 Oct.
84)
Tho. Hoy
(17 Feb. 84–5)
Robert Cowcher

John Wallis
Ralph Bathurst
Hen. Beeston
Tho. Smith
Rob. Plot
Wm. Gibbons
Edward Bernard
Jos. Pullen
Joh. Caswell
Tho. Pigot
Sam Des Maisters
Jo. Ballard
William Musgrave
H. Welsted

John Massey
(Merton, 26 March 84)
Joshua Walker
(B.N.C. 26 March 84)
Tho. Lane
(Merton, 26 March 84)
Will. Levett
(Magd. Hall, 8 Apr. 84)
N. Crowch
(Balliol, 8 Apr. 84)
Hen. Pigot
(Wadham, 8 Apr. 84)
Ar. Charlett
(Trin. 22 Apr. 84)
Steph. Hunt
(Trin. 22 Apr. 84)
Maurice Wheeler
Edm. Entwistle
(22 Apr. 84)
Thomas Creech
(All Souls, 14 Apr. 84)
Hugo Todd
(Univ. 3 June 84)
John Benbrigg
(Univ. 3 June 84)
J. Cunninghame
(St. Leonard's Coll., S. Andrews, prop. 17 June 84)

Members and others elected later do not appear to have signed the book; among these were:

Dr. Aldridge	Original member.
Dr. Bagly, Worcester Coll.	29 Apr. 84.
M. B. Packer, physician of Reading	27 May 1684.
— Mackell	14 Oct. 1684.
— Cole, of Bristol	10 March 1684–5.
William Coward, Merton	16 June 1685.
Charles Standard, Merton	,,
William Deedes	
— Bonnie, St. John's	13 April 1686.
Dr. Edw. Tyson	15 June 1686.
Dr. Tankred Robinson	15 June 1686.
Francis Aston	15 June 1686.
John Flamsted	15 June 1686.
St. Geo. Ash, of Dublin	15 June 1686.
Christopher Pitt	15 June 1686.
Thomas Ludford	1687.

They meet every Tuesday in the afternoone, by the permission of the government, in the Natural History School. The present officers are WALLIS, President; PLOT, Director of Experiments; WM. MUSGRAVE, Secretary; BALLARD, Treasurer; which officers hold their place for a yeare. St. George's Day (April 23) is the anniversary day of election. No one of the University is admitted who is under the degree of M.A. or B.C.L. The way of admission and debate is as at the Royal Society.

In 1688, the officers were:

Dr. BATHURST, President.
MUSGRAVE, Director of Experiments.
ENTWISTLE, Treasurer.
COUCHER, PITT } Secretaries.

The Second (and last) Ashmolean Professor

Plot's resignation of the Chair of Chemistry was accepted by the Vice-Chancellor in November 1689, and Mr. EDWARD HANNES of Christ Church was appointed to succeed. Mr. White retained his post as assistant in the laboratory, and to add to his shortcomings—of which more hereafter—he appears to have considered the property of the University as his own. At least, that is a possible inference from the following hitherto unpublished letter of Plot's, written some years after his retirement from the professorship. The letter is, moreover, of interest because of the description of the equipment of our first University Chemical Laboratory.

Part of a L$^{r.}$ from Dr. Plot, dated Lond. 8$^{br.}$ the 5th, 1695:

"As for the Goods or Utensils in y^{e} Laboratory: the great Alembic, Barrel and Worm, were bought by the University: and so were the great Pewter and small Copper Heads of the Balneum Mariæ, and the Iron pots at the bottom of the Chappel Furnaces. All the ironwork of the Alkanor, and Great Reverberatory was also bought by the University, and all the Furnaces buylt at their charge. The great iron digester at y^{e} West end of the Laboratory is also theirs; and perhaps some things more that are now

out of my mind, the small earthen and Glasse-vessels being onely Mr. Whites. If I were with you I could determine this matter with more accuratly." (MS. Ashm. 1819.)

On July 7, 1690 the new professor, Mr. Edward Hannes "made his inauguration speech in the *Musæum in schola experimentalis philosophiæ* in order to read chimical lectures loco Plot. No programme stuck up; about 20 auditors," including:

Dr. Ralph Bathurst.
Sir George Mackenzie.

Ten days later, Ashmole, who had been taking a cure at Bath, but was still very feeble, was given a banquet, at which Mr. Edward Hannes "spoke a speech to him. Mrs. Ashmole, Jack Cross and Mr. Sheldon dined togeather in Dr. Plot's study."

The standard text-book read by students at the end of the seventeenth century was the *Cours de Chemie* of Lemery, which appeared in 1675, passed through thirteen editions in the author's lifetime, and was translated into English by James Keill, the anatomist, in 1698. This translation introduced English chemists to the current theory of the relations of acids and alkalies.

The cost of chemical apparatus at this time is entered in the diary of a Cambridge man, Abraham De la Pryme, who wrote that he had 'got little or no good' from the course of the Veronese, John Vigani,[1] 'by reason of the abstruceness of the art.'

Feb. 14, 1694: "This day I received twelve little retorts and three receivers from London, to try and invent experiments, and all the things that I shall do I intend to put down in a proper book, and in imitation of the most learned Democritus, to give them the title of χειρόκμητα, as he did his, which being interpreted implys the Experiments of my own personal trying. The retorts cost me 4*d.* a piece at London, and the receivers 6*d.*, and I pay'd for their carriage from thence hither 1*s.* 6*d.*"

Bentley soon afterwards fitted up a laboratory for Prof. Vigani in the 'lumber hole' eastward of Trinity bowling green.

[1] Wordsworth, *Scholæ Academicæ.*

V

EIGHTEENTH-CENTURY SCIENCE-TEACHING

THE effect of the great and stimulating advance which was made in science during the last half of the seventeenth century is manifest in several ways in the beginning of the eighteenth century.

The widespread interest in science is shown, for example, in the long list of subscribers to such a work as Harris's *Lexicon Technicum* 1710, in the purchase of scientific instruments by wealthy patrons such as Charles Boyle, Earl of Orrery, whose collection is still preserved at Christ Church, and in especially favoured localities where, as in the 'elaboratory at Trinity College, Cambridge,' Stephen Hales was able to find an environment congenial to his scientific labours.

In comparison with the advance in experimental science made in Oxford during the seventeenth century, the eighteenth appears an age of languor and neglect. The decline had already set in before the end of the seventeenth century. "Why do few or none follow serious learning in the University?" asked Wood. "Answer, Because of coffee-houses, where they spend all their time; and in entertainments at their chambers; also great drinkings at taverns and alehouses, spending their time in common-chambers whole afternoons, and thence to the coffee-houses."

As regards our predecessors in science, we do not believe Wood's explanation to contain the whole truth. The advancement of learning, like the waters of the incoming tide, sweeps onward in waves, the backflow marking a period of pause and apparent retrogression. The after-effects of the Restoration helped on a natural

reaction against the scientific activities of seventeenth-century Oxford. For many years the output of research was insignificant; but the teaching of natural philosophy was becoming systematised. We have compiled these notes in illustration of the methods of the lecturers, as a first instalment towards a history of academic science in a century that was, scientifically speaking, so unproductive in Oxford. The reason of this sterility was not far to seek. The Oxford contemporaries of Newton had not his enquiring mind; the most brilliant of her sons devoted their genius to other ends and developed their talents in other places; those who stayed behind were content to accept the statements of others without testing them for themselves, and to pass on to their students information acquired at second-hand. The business of teaching was set higher than the duty of research.

The illustrious societies of the preceding century were strangely parodied by "A kind of Philosophical Club set up in Oxford, in imitation of the free-masons and free-sawyers, who call themselves *free-cynics*, and have a set of symbolical words and grimaces, unintelligible to any but those of their own society."[1] May 21, 1737.

The various branches of natural science had by now become fairly well defined and their various aims fairly well understood, even among the non-scientific in Oxford, owing to the foundation of professorships. Chemistry alone of the great sciences was left without a professor, owing to the failure of the well-intentioned, though insufficient and unsupplemented endowment of Ashmole.

The courses of chemical lectures in the Ashmolean were continued by JOHN FREIND, M.D., of Christ Church, in 1704, and were afterwards published in Latin and English.[2] The Latin version was dedicated to Newton,

[1] MS. Rawl. quoted in *Oxoniana*, iv, p. 245.

[2] *Prælectiones Chymicæ: In quibus omnes fere Operationes Chymicæ ad vera Principia et ipsius Naturæ Leges rediguntur, Ann.* 1704 *Oxonii in Museo Ashmoleano habitæ*, a Johanne Freind, M.D. Æd. Christ. Alumn. Londini 1709. 2nd Edit. 1726.

Chymical Lectures: in which almost all the Operations of Chymistry are reduced to their True Principles and the Laws of Nature.

Read in the Museum *at* Oxford, 1704. Englished by J. M., London, 1712.

a compliment duly returned twenty years later by Professor Mickelborough of Cambridge, who began his chemical course with a very proper encomium on Dr. Freind, " the first who applied the Newtonian philosophy to chemistry" (Caius Coll. MSS. 619). " Well-skill'd in Speculative and Practical Chymistry," as the alchemist George Wilson described him, Dr. Freind divided his subject into nine lectures:

Lecture 1. *Of the Principles and Operations of Chymistry.*
,, 2. *Of Calcination.*
,, 3. *Of Distillation.*
,, 4. *Of Sublimation.*
,, 5. *Of Fermentation.*
,, 6. *Of Digestion.*
,, 7. *Of Extraction.*
,, 8. *Of Precipitation.*
,, 9. *Of Crystallisation.*

He expressly states in his preface that the principles of attraction by which he explains the facts of chemistry had been recently explained by John Keil,[1] " to whom not only myself, but the Learned are much indebted." But the book is better than a mere résumé of lectures; it included tables of physical constants, the results of his own researches.

" I have employ'd all the Care and Diligence that I cou'd in making the Tables and Experiments. For 'tis not a thing that can be done without a great deal of Pains and Patience. Therefore I have often willingly had the Assistance of Dr. RICH. FREWIN,[2] a Person every way worthy of the Place that bred him, and very well vers'd in all sorts of Learning, especially those which relate to Physick."

The results are set forth in three tables:

Table 1. Rarefaction, Ebullition, and Ascent of Liquids.

[1] *Theoremata de Vi Centripetâ*, *Phil. Trans.* No. 317.

[2] Richard Frewin, Ch. Ch. 1698, B.A. 1702, M.A. 1704, B.M. 1707, D.M. 1711. Camden Professor of Ancient History, 1727–61. He owned a copy of Borrichius' *Hermetis Ægyptiorum et Chemicorum Sapientia . . . Vindicata.* Hafn. 1674.

Table 2. Specific Gravity of Solids.
,, 3. Specific Gravity of Liquids.

Little is known concerning the sources whence the operators of this period derived the chemical substances for their experiments. We are informed by C. Erndtel, *Relation of a Journey* 1706–7, that "all the Apothecaries take their Medicines, as well the great Compositions as the Chymical, as their operations require" from the Laboratory of the Apothecaries' Hall. Godfrey had been Master of this Laboratory, but in 1706 was living near Covent Garden. He informed Erndtel of the pains that he (or Boyle) had taken in preparing Phosphorus and of the "advantage of English Pewter, which being made of Martiated Regulus of Antimony, Copper and Bismuth of equal parts, composed the best Pewter."

In Oxford drugs were still procurable at an apothecary's opposite or near All Souls College, mentioned by the traveller Uffenbach as being partly used to house the Codrington Library (October 7, 1710). It was probably Arthur Tillyard's house, already mentioned.

The information at our disposal about the state of chemical studies in the beginning of the eighteenth century is derived from this unappreciative and somewhat inaccurate German, who found much to condemn in the England of 1710. His pages give one the impression that English cooking did not always agree with him. But his picture of the dirt and disorder of the Ashmolean Laboratory is probably a true one.

Uffenbach had just been to hear Lavater's Anatomy Lecture in the small vaulted room under the Ashmolean and behind the Laboratory, which, by reason of the cool temperature, was well adapted to anatomy.

"When the lecture was over, we proposed to see the laboratory, and all the more because Dr. Lavater would be able to explain everything, and to demonstrate clearly the purpose and use of everything, but he excused himself as not knowing the uses of all the apparatus; and so it appeared to me that Mr. Lavater was not as good a chemist as an anatomist, for he over-

praised Lemery's *Cours de Chimie*, which I altogether distrust on account of his Curiositez in 8, in which there are innumerable things which I have found impossible to do well. But Dr. Lavater maintained that the book was not by Lemery but by his son, and that nothing was contained in his *Cours de Chimie* but what was considered correct, and proved by the Society.[1]

"But to return to the Laboratory. I must say that it is right well built. It is as long or deep as the Ashmolean, but not as broad. It is completely vaulted over, and is provided with many kinds of furnaces, some quite remarkable, all of which are decorated in the most costly manner with architectural decorations and the like. The greater number were presented by Boyle. For it should be known that this laboratory was originally used by the Royal or London Society, when it was most flourishing, and that many excellent researches and discoveries were made here. But since the Society has become proud and great, and has removed to the capital, as frequently happens, it has decayed, as will be explained later. It is, moreover, regrettable, that after the Society had wholly removed to London, this excellent laboratory should not have been maintained in the condition in which Benthem (p. 350) found and praised it. The present Professor of Chemistry, Richard Frewin, does not trouble much about it, and the operator Mr. White (said to be a good-for-nothing man) still less. And so, although the furnaces are in fairly good order, they look very much the worse for wear. Not only are the finest instruments, tiles, and such like almost all broken to pieces, but the whole place is filthy. Is it credible that so little attention should be given to so costly and beautiful a work? Who could have believed it in England, which over-sea has so high a reputation, where all studies, and chemistry in particular, are believed to be flourishing in the utmost

[1] The first edition of Nicholas Lemery's *Cours de Chimie* was approved by the Faculty of Physick in Paris in 1675. The eleventh edition appeared in 1716. An English translation by Walter Harris appeared in 1677. The fourth edition of a second English version, perhaps the one in which Keil had a hand, was dated 1720.

perfection? It is strange that Gottfried[1] (of the Strand) in London, a German by birth, and a Venetian Jew, should have finer and better laboratoria in London, than the Royal Society and the apothecaries, which are so highly thought of by the English, especially in Nieu kew of London."

Dr. Wall and Porcelain

In spite of the unsatisfactory state of affairs disclosed by Uffenbach, we cannot help thinking that another of the great industries of England owed its origin to furnace-chemistry in the Ashmolean. Just as salt-glazed stone-ware was the discovery of John Dwight of Christchurch, so Worcester China was evolved by Dr. Wall of Merton.

Dr. John Wall (1708–1776) was doubtless familiar with the laboratory, either as an undergraduate at Worcester College in 1726, or later when he was preparing for his medical degrees as a Fellow of Merton College in 1735. It is only as a medical writer that he was known to his biographer in the *Dictionary of National Biography*, but, thanks to his knowledge of chemistry, and to his unusual artistic talents (he designed the stained glass windows at Oriel College), he will always be remembered for having added to the fame and prosperity of the City of Worcester by founding the China Factory.

Probably in the forties he "turned his attention to experimenting on materials which might be used for the manufacture of porcelain; and in 1751, about a year after the establishment of the works at Derby, and while those at Chelsea and Bow were being carried on, brought those experiments to a successful issue by the discovery of a body of surpassing excellence, and at once formed a company for its manufacture."

The "Worcester Porcelain Company" thus founded, in 1751, appears to have first consisted of Dr. Wall, Richard

[1] Godfrey sold some of his preparations at the following prices:

Spirit of Lavender . . .	5*s*. per oz.
English Salt . . .	1*s*. per oz.
Phosphorus . . .	8*s*. per drachm.

Holdship, the Rev. Benj. Blayney, and Samuel Bradley. They commenced operations at Warmstrey House, whose grounds run down to the banks of the Severn, and at first produced imitations, both in form and colour, of the blue and white patterns of Nankin porcelain. The brilliant colours of the Japanese were, however, soon attempted, and with complete success; and, by the conventional arrangement of these colours in new patterns, the Worcester potters were gradually led on to more elaborate productions.

The early ware was characterised by a peculiar soft greenness of body, and bore a mark, a simple W, which may either have been the initial of its founder, *Wall*, or of the City, *Worcester*, itself.[1]

A picture of his works appeared in the *Gentleman's Magazine* in 1752 (Jewitt, *Ceramic Art*). His medical works were published in a collected form by his son, Martin Wall, whose chemical lectures are described below.

We have now arrived at that part of the century when the intellectual outlook of Oxford was at its narrowest. Whether this was the result of the misspent hours in the coffee-houses, as Wood has suggested, or whether Hearne was right when he attributed the miserable decay of good letters to the colleges being engaged in law businesses and quarrels, is immaterial; the Oxford of that day had ceased to take any part in contemporary chemical discovery and discussion. We should like to think that this aloofness was the result of mistrust of the popular phlogistic theories that then prevailed, but we fear that the explanation was a more materialistic one.

Owing to the non-existence of a regular University professor of chemistry, medical students and others obtained instruction partly from laboratory operators and partly from anatomy readers. The course of Dr. Smith, a young M.D. of St. Mary Hall, and afterwards Savilian Professor of Geometry (1776–97) is known from the lecture-notes of a Merton undergraduate now in the Bodleian Library.[2] The style and standard of the

[1] One of the best collections of Worcester China of the 'Wall Period' (1751–83), is that of Mr. F. Dyson Perrins, the founder of the new Chemical Laboratories in Oxford.

[2] Add. A. 302. Geo. Wingfield, matriculated 1755, *d.* 1774.

lectures may be gathered from his description of two of the mineral waters found near Oxford.

Anatomical Lectures just as they were taken at a Course read by Dr. Smith of St. Mary's Hall, Oxford, in the Laboratory 1759*: by* Geo. Wingfield *e. coll. Mert. Oxon* 1759.

P. 139. "If you take *Cumner Water* and put to it Syrop of Violets to see whether it is an Acid or an alcali, if it turns Red, you are sure there is an acid in the water, but if it turns green you can't be certain that there is an alcali; This *water* is supposed to abound with an alcaline salt; if you pour in an acid to try if there will be any effervescence, there will be none, whereas if the water was alcaline there certainly would be an effervescence; tho' it has always been supposed to have had an alcali in it.

"Try whether there is iron in it by adding the Tincture of Galls; it turns brownish so there is a little Iron in it.

"Try whether it has a Neutral Salt, by adding a solution of Silver and fixed alcali as Lix: Tartari, and it strikes the same appearance as with sea salt, which shows there is a neutral salt, and upon Evaporation it is found that Cumner Water has in it a *Glauber Salt*; this water is a gentle Purgative.

"*Holliwell Water.*[1] When mixed with syrop of Violets turns green, tho' most metalline waters do this whether they have an acid or alcali in them: so that tho' their turning red upon syrop of violets being put to them is a sure test of there being an acid in them, yet their turning green is by no means a sure sign of their having an alcali.

"Try this Holliwell Water with Tincture of Galls, it strikes a black colour, which shows there is a great deal of iron in it.

"Try it with Lix: Tartari, or a sol. of Silver: with Lix. Tartari it grows cloudy, which shows there is a gentle impregnation with some neutral salt: A solution of silver is an elegant Test to try it with."

P. 144. "We now come to treat of a chymical production called Phosphorus: which is very singular, curious and extraordinary: tho' but of little use to the world otherwise than explaining in Philosophy some phenomena not otherwise known."

. . . . .

[1] In 1738 a mineral spring had been found in Holywell, "very strongly tinctured with steel, answering to all the experiments tried on waters of that kind, being tinged with a deeper purple colour than most chalybeate waters. Divers infirm persons have found benefit by them." (Hearne.)

"The Urinous Phosphorus was discovered accidentally by one Brand of Hamburgh, he long searched after the Philosopher's Stone: and urine being a remarkable pungent thing, he thought an extract or spirit from it would be a very lightly thing to change the baser metals into gold: he tried it in all ways for several years; and at last was greatly surprised to [see] a lucid flame come over into the receiver, which it filled with a luminous appearance. He now thought he had certainly got the Philosopher's stone. This greatly surprized all the chymists, and among the rest especially Dr. Cunckham, a very great chymist in Germany, he endeavoured for 4 years to find this out, and at last hit upon it; Some of it came over to England, and *Mr. Boyle* was very desirous to find it out and after some time got the method of making it. Some persons thought *Cunckham* had told him of it; others that he found it out himself; *Godfrey* however, as he was Mr. Boyle's chief manager learnt this receipt; So that Brand, Cunckham and Boyle being dead, the making of phosphorus remained solely in Godfrey's hands; he supplying all Europe with it, which supported himself and family till within this late. *Godfrey*, however, being a man of expence and pleasure, went over to France where it is supposed he discovered this art for a sum of mony, as a little after a Frenchman published a book about it.

"Boerhave gives a long account of this Phosphorus in his works, but it is plain from his account, he never made a grain of Phosphorus.

"Brand, Cunckham, Boyle and Godfrey were all the people in the World who then knew how to make this Phosphorus."

[Cunckham is evidently a mistake for Kunckel.]

The next chemical achievement of local interest which we have to record was not without its commercial side. Samuel Glass, a surgeon in Oxford, published a pamphlet entitled *An Essay on Magnesia Alba*, Oxford 1764, of which a copy is preserved in the Christ Church Library. The compound was moreover described as "Prepared by S. Glass and sold by him as usual in Oxford in Guinea, Half-Guinea, and Six-shilling Boxes." The same commercial spirit has been known to pervade modern chemistry—coal gas, poison gas, and coal-tar dyes have all their modern values.

In 1781 Martin Wall, M.D. (*b.* 1747, *d.* 1824), an

Oxford physician, who had been a Fellow of New College, secured the appointment of Public Reader of Chemistry in the University four years after taking his degree as a doctor of medicine. He delivered, and afterwards published:

I. *An Inaugural Dissertation on the Study of Chemistry: read in the Natural Philosophy School,* Oxford, May 7, 1781, which he followed with *A Syllabus of A Course of Lectures in Chemistry, Read at the Museum, Oxford,* 1782; and with *Dissertations on select subjects in Chemistry and Medicine*; 8vo Oxford, 1783.

We have a favourable testimonial to the educational value of Dr. Wall's lectures, in the ingenuous letters of John James of Queen's College. Dr. Wall appears to have impressed his class with the thought that chemistry is " an immediate revelation from Heaven to Adam, and had its name from Cham, the progenitor of the Egyptians," so that it is not surprising that James, after many terms' experience of the insufficiency of teaching in his college, became enthusiastic about chemistry, a subject which " promises to afford a firm and elegant basis for a compleat skill in Natural Philosophy, . . . and certainly will enable any divine in Europe to describe with confidence the operation by which Moses might have reduced the golden calf to powder—to the confusion of Voltaire and all his disciples." [1]

Our curiosity to know more of Dr. Wall and his illuminating lectures was only partly allayed by the discovery in the Radcliffe Library of some brief MS. *Minutes of Dr. Wall's Lectures in Chemistry*, but there is a fuller account both of the personality of the lecturer and of his lectures in the letters of John James to his father. James found him sensible and courteous, with a family " where I shall go to relax and domesticate

[1] Wall also published the following papers:

" Conjectural remarks on the symbols or characters employed by astronomers to represent the several planets, and by chemists to express the several metals." [1782.] *Manchester Phil. Soc. Mem.* i. 1789.

" Remarks on the origin of the very fixed alkali, with some collateral observations on nitre. [1783.] *Manchester Phil. Soc. Mem.* ii. 1789.

" Some observations on the phenomena which take place between oil and water." [1784.] *Manchester Phil. Soc. Mem.* iii. 1789.

myself with the sound of clocks, females, and children" (July 15, 1781). Dr. Wall had delivered his inaugural lecture (gratis) on May 7, 1781, some time before James presented his letter of introduction from Dr. William Brownrigg, F.R.S. (*b.* 1711, *d.* 1800), a learned chemist of Cumberland, whom Wall spoke of as "immortalized for his experiments." (See *D.N.B.*) James, however, borrowed the notes and resolved to take the course of lectures at three guineas. They commenced on Monday, October 13. (*Jackson's Oxford Journal.*)

Wall's First Lecture on Chemistry

Audience: fourteen or fifteen, including John James.

"The uses of Chemistry. Chemistry is the Study of the effects produced by heat and mixture.

"Chemistry has improved Science . . . given occasion to the invention of gunpowder, and a *coup de grâce* to y^{e} miseries of war.

"It mingles itself with all the arts in which fire or mixture are employed; the dyer, refiner, painter, smith, and the cook himself are all in some degree chemists. But its most eminent powers are reserved for medicine. . . . With respect to the history of the art, it is by some supposed to have been an immediate revelation from Heaven to Adam, and to have had its name from Cham, the progenitor of the Egyptians, amongst whom it is thought to have flourished. The two most remarkable periods in the history of chemistry are the dark ages, in which it was strangely worshipped and abused by the alchemists, and the era when it was rescued and reformed by the efforts of Lord Bacon, the Morning Star of all philosophy. . . . The definition, selected as the best of many celebrated, is that of Doctor Black, that 'Chemistry is a science teaching by experiment the effects of heat and mixture upon bodies.'"

This lecture was peculiarly entertaining from the selection and novelty of the facts, but it was not original, nor well written, being far too declamatory.

Lecture II and III, October 30 and 31. On the expansion of metals; the communication of heat; thermometers; the rarefaction of air and other fluids by heat; the nature and causes of cold fluidity; absorption of heat necessary to fluidity; latent heat.

Lect. II, *Heat.* "Wool has no heat in itself, as is seen by its keeping ice cool." (Minutes of Lecture in Radcliffe Library.)

J. to Mrs. Boucher

"*November* 13, 1781.

"It is unfortunate for us that the Doctor is tied down to a single hour, by which means his lectures are read with a rapidity that prevents much from being remembered, and anything from being taken down.

"Were I not assured that all such offers were useless, and afraid they might seem quackish, I should make you a tender of my newly acquired chemical knowledge. . . . There are numbers of receipts to make this charming medicine (the universal elixir), but by some strange fatality one half is unintelligible, and the rest unsuccessful. The only one I am possessed of, the ingredients of which are sea-salt and flints, has not obtained much credit with the world, merely because the unfortunate man who invented it died by an *incurable* disorder at the age of forty-eight."

J. to J. Boucher

"*November* 18, 1781.

"The business which most interrupts my study of the Greek Testament is the chemical lecture. It promises to afford a firm and elegant basis for a compleat skill in Natural Philosophy; it may furnish variety of hints, allusions, expressions in every kind of composition; and it certainly will enable any divine in Europe to describe with confidence the operation by which Moses *might* have reduced the Golden calf to powder—to the confusion of Voltaire. . . . Wall is a scholar, and understands how to diversify his compilations, for such you may suppose they *must be*, with elegant learning. He sometimes intermingles a spice of divinity, if observations on some names of chemical substances in the Bible may be so called. We had, for instance, on Friday an enquiry into the nitre mentioned in the twenty-fifth Proverbs, which appears to have been a substance entirely different from the nitre of the moderns, *which does not effervesce with vinegar*, and seems to have been unknown to the ancients in general. The nitre there described was most likely an alkaline salt, the *natron* of Egypt, where it is found native, which at the same time that it is affected by acids in the manner alluded to by Solomon, has detersive properties, and is therefore fit for

baths, to which purpose we learn from Jeremiah it was applied by the women of the East."

Dec. 12, 1781.—"No lecture on Thursday and Friday. Divines who have studied chemistry Stephen Hales (1677–1761, F.R.S. Fellow of Corpus), Dr. Richard Watson, Fellow of Trin. Cam. 1760, Professor of Chemistry 1764, Regius Professor of Divinity, 1771, author of *Institutiones Chemicæ.* Dr. William Adams, Master of Pembroke, "considerably deep in chemistry" (Wall).

"A large part of our present class consists either of clergymen, or men intended for the Church; and it is the advice of some tutors here, . . . to obtain some knowledge of this science previous to the study of Natural Philosophy."

"*J. James to his Father*

"*December* 12, 1781.

"... Our course of chemistry which was to consist of 27 lectures is now approaching to a conclusion. The class has hitherto held out pretty well: our numbers are however beginning to fall off daily. From his success in this first attempt the professor has conceived greater expectations from a second. He certainly merits encouragement from his diligence, modesty, and the real excellence of his instructions. For the most of what he delivers is to be found in the readers of chemistry, and he can pretend to no original discoveries of new theories, still he has the merit of collecting curious information, scattered through a number of books, which if we could procure, we could not, perhaps make any use of. Besides, it requires considerable skill to be able, from a heap of facts, to select such alone as have a just connection with the subject, to choose the best, or most probable of contending theories, and to give an uniform and regular appearance to a mass of matters from a thousand different authors. All this the Doctor seems to have performed as successfully perhaps as a first attempt will admit. . . . Perhaps no man can be a compleat philosopher or physician without a knowledge of chemistry. There having been no unexceptionable arrangement of the particular objects of chemistry, the professor assumed the privilege of introducing a new one of his own, I believe. . . .

"The present arrangement consists of six heads. (1) Saline Bodies; (2) Earthy; (3) Inflammable; (4) Metallic; (5) Aerial; (6) Aqueous.

"Animal and vegetable substances are omitted, because they may be reduced to four elementary substances.

"An analysis is only then perfect when by the reunion of the separated parts the original substance is revived.

"No art has yet been able to produce any animal or vegetable substance by any combination, or modification of their parts.

"'Let all those heroes of science meet,' says Boerhave of the chemists; 'let them take bread and wine, a food that forms the blood of man and by assimilation contributes to the growth of the body. Let them try all their arts: they shall not be able from these materials to produce a single drop of blood.'"

"This challenge of Boerhaave, the wisest of the chemists, was in consequence of the foolish boastings of some adepts, that by means of artificial heat and digestion they could imitate the works of God."

Dec. 26, 1781.—"In a late lecture Doctor Wall made some remarks on solvents in general, which, tho' dubious, or weak in their operation, he observed have undoubtedly a power of relieving pain in a very surprising manner. He seemed also of opinion that a discovery may possibly be made of a solvent to act on the stone without injury to the body; similar to that digestive liquor of the stomach, which, at the same time that it destroys and macerates substances of great hardness, has no action on the part where it resides. Our chemical lectures ceased some days ago."

No date (? Jan. 1782):

"The frost is however commenced; my shoeblack informed me to-day that the bell-rope was a quarter of a yard longer than yesterday evening, an evident proof of the approach of dry weather.

Jan. 22, 1782.—"From my windows I can observe an adjoining garden in which there are several lilachs ready to burst into leaf. . . . I mean to resume a project hatched last spring for determining the difference of the time of vegetation here and in Cumberland. For this purpose we should agree to observe the flowering of the same plants. The most common and observable flowers will be most proper: and if I can prevail on any of the family to choose their flowers, and give me a list of them, and then take a peep once a day at each we may make out something like a probable calculation.

"In return, I am preparing a list of early and common plants to assist in making the selection.

"Am I to attend Doctor Wall's second course of chemistry which begins the 12th of next month? Terms two guineas, after which I shall be free of them for ever."

In June 1784 "this learned, ingenious and pleasing gentleman" drank tea with Dr. Samuel Johnson.

The following extracts are from the Radcliffe Library version of Notes from Dr. Wall's lectures:

Various receipts. "Pounded ants afford an animal acid equal to half their weight." "Nitre is y^e basis of fulmination in all substances that detonate—*ergo,* the anc^t. or early Chym. attribd. *thunder* to a *nitrous acid* in y^e air w^ch. is not true. Bricks, Porcelain."

"Tea acts on iron by infusion and becomes black as in ye case of ye sugar broke by ye rusty knife at Worcester."

"'Gas, Gasche, Gaist, Ghost—spirit,' Van Helmont gave this name."

"Gold: Mr. Homberg pretended to have vitrified gold in ye focus of a Concave mirror, but no one has been able to do ye same thing since with better glasses. Gold is to water as 19 to one."

Meanwhile it is scarcely to be wondered at that a contemporary of Dr. Wall's was "the last of the alchemists" in active pursuit of 'transmuted' gold at Stoke, near Guildford.

JAMES HIGGINBOTHAM, afterwards James Price of Magdalen Hall, 1773–7, M.D., F.R.S., still blushing with the "recent honours, with which the University, to whom he owes his Education, has crowned his Chemical Labours" (he became a Doctor of Medicine on July 2, 1782), published an *Account of some experiments on Mercury made at Guildford in May* 1782 *in his Laboratory.* The gold left at the end of the experiment was tested and weighed by Mr. Lock, an experienced goldsmith and a magistrate of the City of Oxford. Mr. Walden has drawn my attention to the tragic end of James Price; he gave his life for *his* science. He was called upon by the Royal Society to repeat his experiments before a Committee. The experiments failed, and James Price committed suicide.

But as the first decade witnessed the gradual squandering of the spirit of enquiry that was so eminently a characteristic of the stirring times of the seventeenth century, so in the last decade we find indications of progress towards the boasted superiority of the nineteenth century.

In 1788–93 the University found a reader of a more scientific turn of mind in the person of Dr. THOMAS BEDDOES. He lectured on chemistry, and also on strata and rocks, and drew the largest classes known in the University since the thirteenth century.

Although during the short tenure of his Readership he did not contribute to the extension of chemical knowledge, yet it must always be remembered that Beddoes upheld the honour of the Oxford chemical school by printing *Chemical Experiments and Opinions extracted from a work published in the last century* (by Mayow) in 1790, immediately after the appearance of the *Traité de Chimie* of Lavoisier, whose views on combustion had been practically forestalled by Mayow by the assumption of a spiritus igno-aereus or nitro-aereus.

Two letters from Beddoes were printed by G. D. Yeats, M.B., of Hertford Coll., in *Claims of the Moderns to Discoveries in Chemistry and Physiology.*

The name of Dr. Beddoes will always be remembered as that of the friend and patron of the best-known chemist of his day. In 1798 the post of superintendent of the 'Pneumatic Institution' at Clifton, was practically in Beddoes's gift, and he recommended the appointment of Humphrey Davy. In a year, by incredibly hard work, Davy had concluded his classical research on nitrous oxide, and had discovered and investigated its remarkable anæsthetic properties.

In 1789 and in several following years an ingenious native of Oxford, *Mr. Sadler* (afterwards known as 'the Aeronaut'), gave lectures on what he called 'philosophic fire-works'; the taste for *hard words* of Greek formation had not yet set in, or he would probably have called them 'pyrotechnics.'

"Mr. Sadler was a clever, practical, and experimental manipulator in chemistry, and as such was patronised

by the University, or rather by the few scientific men then in the University; what the University, as such, did or even professed to do in scientific matters at that period it were hard to say." (Cox, *Recollections*, p. 8.) But, before we stigmatise Mr. Sadler's methods as unscientific let us remember that only a very few years before, Humphrey Davy "had entered the study of chemistry through the doorway of fireworks."

A remarkable likeness is to be traced to the lectures at the sister University. At Cambridge W. Parish, the new Professor, announced his intention of lecturing on the Application of Chemistry to the Arts and Manufactures of Britain. "Having provided himself with a number of *Brass Wheels* of all forms and sizes, such, that any two of them can work with each other, the *Cogs* being all equal; and also with a variety of *Axles*, *Bars*, *Screws*, etc., he constructed at pleasure Working Models." . . . A Meccano outfit in short. . . . "The methods of obtaining *Coal* and *Sulphur*, the arts of working *Animal* and *Vegetable Substances*, the construction of *Bridges*, and *Naval Architecture* and much else besides were all explained in this fascinating chemical course. Thus, by drawing the minds of persons to the consideration of the most useful inventions of ingenious men, he designed to enlarge their sphere of amusement and instruction and to promote the improvement and progress of the Arts."

In 1794 Dr. Beddoes was succeeded in the Chemical Readership by another eminent physician, Robert Bourne, M.D., who had obtained his diploma of M.R.C.P. on Sept. 30, 1790.[1] It was a period when the new

[1] My friend the present Professor of Comparative Anatomy, Prof. G. C. Bourne, has written to me the following interesting note on his great-grandfather, Robert: "It is of him that Mozley, in his *Reminiscences, chiefly of Oriel College and the Oxford Movement*, says that 'once, finding himself despised for his youth, his good looks, and gaiety of manner, he had disappeared for a month and then reappeared with a wig, a grave tone, and a more measured utterance.' The 'month' is clearly an error. My great-grandfather 'disappeared' abroad, I believe to Amsterdam, for a year or more, where he went through advanced studies in Medicine and Science, which no doubt were the qualifications which led to his appointment to the Readership in Chemistry in 1794. He afterwards became Aldrichian Professor of

Radcliffe Infirmary doubtless gave a great impetus to the study of medicine, and thereby to chemistry, and the teachers were primarily medical men.

Dr. Bourne's first course was described in:

A Syllabus of a Course of Chemical Lectures read at the Museum, Oxford, in 1794.[1]

"The Course will be practical rather than theoretical."

Terms of attendance are, for the first and second Courses, three guineas each; for any future course, one guinea.

An Introductory Lecture to a Course of Chemistry read at the Laboratory in Oxford, on February 7, 1797, dealt chiefly with the Utility of Chemistry. The "Study of Chemistry may be useful to the different descriptions of Gentlemen, who resort to the University as a place of education, to Gentlemen of Fortune, to Students in Divinity, in Physic, or in Law."

"Many of the former will become M.P.'s, and have to decide on questions, highly interesting to our Manufacturers and Commerce; others may have a fondness for Agriculture . . . should they improve the state of Agriculture they will feel the advantage in the increase of their rentals. Those Gentlemen of Fortune whose property consists of metallic mines. . . . A Physician, ignorant of Chemistry, cannot be well skilled in his Profession. Object, Perspicuity and general Utility."

In brief, the records of chemical studies in Oxford

Medicine in 1804, and in 1824 Clinical Professor, and died in 1829. He was a considerable figure in Oxford in his day and in great repute as a physician, having a large practice in Oxford and the County, for which last he had qualified by membership of the Royal College of Physicians, a qualification not always possessed by Oxford M.D.'s of that day. He belonged to the school of exact and careful clinic, and kept most careful and exact records of every case he attended—unfortunately, my grandfather thought fit, in 1830, to burn the whole of these records, and I have, in consequence, very few papers relating to Dr. Bourne's medical activities. . . . From all the information I possess about him I regard my great-grandfather as an eminent medical man of his time, but not as an eminent scientific man. He was of the old type, a good scholar, a Fellow of Worcester, and for some time, before he embarked on the practice of medicine, was a classical tutor."

[1] The MS. notes of Dr. Bourne's lectures, taken by S. Rigaud, in 1795, are preserved in the Library of Magdalen College.

during the eighteenth century reveal all the signs of the barrenness of unprogressive science—unprogressive because the spirit of enquiry engendered by intelligent investigation in the laboratory was for the most part dormant alike in teachers and their pupils. Yet elsewhere the age will always be remembered as that of Black in Scotland, Cavendish at Clapham, Priestley in Leeds, Scheele in Sweden, and Lavoisier in Paris.

In London experimental technique was being greatly improved, and chemists were beginning to acquire skill in glass working,[1] upon which the whole of the later developments of the science rest.

In London chemical experiments evidently attracted fashionable audiences, as we see depicted in Rowlandson's plate of Accum's Chemical Lectures at the "Surrey Institution.". This print, Mr. Laurence Binyon informs me, is catalogued by Grego under the conjectural date '1820 (about),' but the atmosphere is that of the eighteenth rather than of the nineteenth century. According to Grego, it is Sir Humphrey Davy lecturing at the Royal Institution. Friedrich Christian Accum was a Westphalian, *b.* 1769, who worked in England 1793—1820 and died in Berlin in 1838. The Surrey Institution was in Blackfriars Road, and is depicted in Rowlandson and Pugin's *Microcosm of London*, pl. 81 (1809).

[1] *E.g.* Peter Woulfe (1727?–1803) invented the bottle which bears his name about 1767. In his later days his laboratory was in his rooms in Barnard's Inn (No. 2, second floor); they were crowded with chemical apparatus. (*D.N.B.*)

VI

THE EARLY NINETEENTH CENTURY

The Aldrichian Professorship

In 1808 Dr. G. Aldrich endowed a Professorship of Chemistry, which was subsequently increased in value by a grant of £100 a year from the Crown.

Kidd, the first Professor, occupied the chair from 1808 to 1822.

His *Syllabus of a Course of Lectures* was printed at Oxford in 1808. The course consisted of twenty-six to thirty lectures, 'which are delivered partly in Michaelmas and partly in Lent Term, at Seven o'clock in the Evening of Tuesdays, Thursdays and Saturdays.'

It should not be forgotten that among those who were smitten with enthusiasm for chemical methods at this period was Shelley, whose rooms in University College were littered with 'books, boots, papers, philosophical instruments, clothes, pistols, linen, crockery, bags, and boxes . . . and a small glass retort above an Argand lamp, which soon boiled over, adding fresh stains to the table, and rose in disagreeable fumes.' His memorial now rests almost on the exact site of Robert Boyle's laboratory.

Shelley and Daubeny both matriculated in the same year, 1810, and both may have attended Dr. Kidd's course, although with far different results.

It is not often that a chemical laboratory provides its workers with the materials for their research from its own fabric, yet the hoary walls of the underground parts of the Ashmolean building provided Dr. Kidd with the saltpetre that he described at length in his

longest paper published in the *Philosophical Transactions of the Royal Society* (1814).

Dr. Kidd and his family had occupied the rooms in the basement of the Ashmolean Museum. In a letter dated June 5, 1817, from Kidd to the Vice-Chancellor he wrote thanking the University for fitting the laboratory as a temporary residence, and expressing his willingness to put it back *in statu quo*. He mentions that he has lately obtained a valuable apparatus for the Chemical School, and an annual salary from the Government for the Professor of Chemistry.

Both of Dr. Kidd's predecessors still retained their interest in the material interests of chemistry. *Martin Wall* and *Robert Bourne*, formerly Readers in Chemistry, wrote a long letter to the Vice-Chancellor concerning a division of the apartments under the Museum between the Professor of Chemistry and the Keeper of the Museum. If subdivided, the interests of chemical science must suffer. They rightly protested at the idea that the Chemistry Reader should be confined to his lecture-room, and to a room to be used by the servants of the Keeper for culinary purposes—humiliating to Science.

The Professor, they wrote, would not have space for his apparatus, nor for his experiments, nor could he take private pupils. What would the Radcliffe Trustee say if he were to visit the place to which their liberal donation of chemical apparatus was consigned? The Professor of Chemistry had used a part of the Museum for his family.

Dr. Daubeny

On October 10, 1822, Dr. Daubeny was elected Aldrichian Professor of Chemistry. He delivered his Inaugural Lecture on the Study of Chemistry on November 2, and then, after the manner of Professors of Science, applied for a grant for his department. His correspondence relating to this matter is preserved in the University Archives, where I have had the opportunity of consulting it through the courtesy of my friend Mr. Poole.

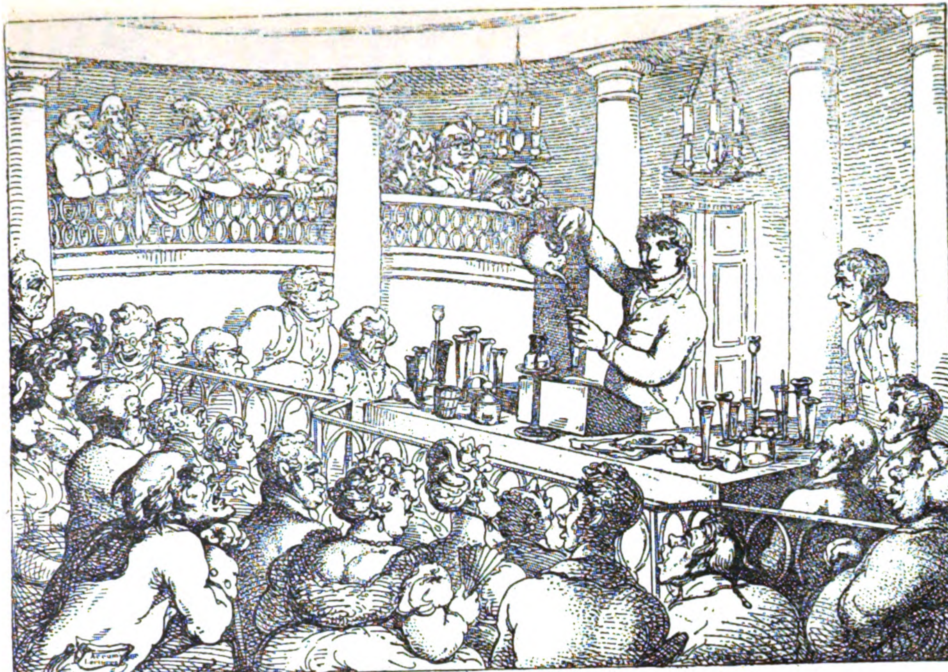


FIG. 11.—ACCUM'S CHEMICAL LECTURES.

"*April* 3, 1823.

"DEAR SIR,

"I enclose a List of the most valuable part of the Apparatus now in the Chemical Laboratory, extracted from a more complete Catalogue which I have lately taken, conscious that in the event of my obtaining the Grant of money for the purchase of fresh Instruments which you had the goodness to submit to the consideration of the Heads of Houses at one of their Meetings in last term, they might deem it satisfactory to be informed as to the condition and amount of the Apparatus at the present time. I should add that although a part only of the Articles enumerated belong to the University, yet that it is my intention to make over the whole in the event of my obtaining the additional allowance which I sollicited in my former letter and am dear Sir with much respect,

"Yr truly obliged,

"C. DAUBENY."

A grant for chemical apparatus was voted in Convocation on April 28 :

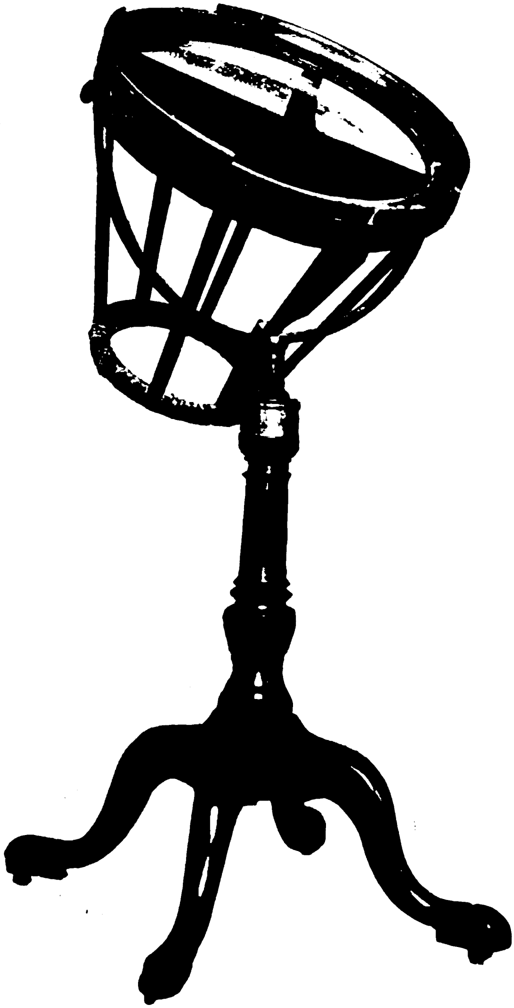
Causa Convocationis erat ut Suffragiis permitteretur utrum summa £200 e Fisco Academico, ad expensas Chemici Apparatus et suppellictillis cujusdam in Officina Chemiæ solvendas, numeretur ; et ut alia negotia Acad. peragerentur.

On the next day he appears to have signed an Agreement.

"OXFORD,
"*April* 29, 1823.

"In consideration of the Grant of £200 voted to me in Convocation on the 28th of April last, I have deliver'd in a complete Inventory of all the Apparatus, etc. in the Chemical Laboratory made out by Mr. Robert Bliss : and engage to take upon myself the payment of all expenses hitherto incurred in the purchase of Fixtures, Apparatus etc. for the use of the Chemical Laboratory, as well as those which may arise until the month of August 1825 including a term of three years from the time of my appointment as Reader in Chemistry. I also make over to the University the Apparatus and Fixtures at the Museum which

DR. C. G. B. DAUBENY.
Aldrichian Professor of Chemistry, 1822–1854.



LARGE BURNING LENS.
Perhaps obtained from Samuel Parker, a London optician.

are my own property, and engage to expend at least half the sum allow'd in the purchase of further apparatus.

"CHARLES DAUBENY,
"*Professor and Reader of Chemistry.*"
[Inventory appended.]

The inventory (18 pp.) is signed by Robert Bliss, April 24, 1828, and Daubeny's signature to the acknowledgment appended is witnessed by the Vice-Chancellor, G. W. Hall. The catalogue is arranged by cupboards, etc., and some of the apparatus, including three dozen wine-glasses and one black lead furnace, was stored on "shelves in Bed-Room."

The more important pieces of apparatus are tabulated in a separate list, which we reprint, with notes in brackets from the more complete inventory.

1 large Airpump } in good condition but { (by Carey, cost
1 small do. } requiring repair { £55 9*s.* 0*d.*)
2 other Airpumps much out of repair.
1 large Burning Lens (16 inch Lens in a black Frame). See illustration.

Electrical Apparatus.

1 small Plate Glass Machine with the necessary Apparatus in a Mahogany Case (by Carey, £16).
1 cylindrical do. (by Nairne).
1 set of Leyden Jars in a Box.
1 Universal Discharger.
5 Electrometers of different kinds.
1 Electrophorus.
1 Faraday's Magnetic Apparatus.
1 Do. of Ampère's with Bar Magnet.
2 jars for burning wire *in vacuo*.
1 Potassium apparatus.
1 Apparatus for decomposing water.
1 large Magnetic Needle w. Stand.
1 Galvanic Battery consisting of 15 Troughs.
150 Prs. of 4 Inch Plates, 100 pr. with double copper (in 10 sets, £16 8*s.* 6*d.*).
50 with single do.

N.B.—There are other Galvanic Plates, but they are nearly worn out. (Old battery had 2 inch square plates.)

Sundry other Electrical, Galvanic and Magnetic Instruments for the most part out of repair, of little value.

1 Prout's Apparatus for the analysis of animal Bodies (cost £40).
1 large Balance (by Corless) of Platina
1 small do. (one cost £20) in Glass Cases.
1 do. of Brass.
2 commoner prs. of Scales and Weights.
N.B. The rest are worn out.
1 large weighing Machine.
1 weighing Table.
A set of weights from ½ cwt. to 8 drachms.
7 large Platina vessels.
7 small do.
4 silver do.
9 Mercurial Thermometers w. Scales.
4 Do. graduated on the glass stem.
8 Spirit do.
1 Metallic do. (Breguet's).
8 Leslie's Differential do.
1 Pyrometer (Wedgwood's).
1 Hygrometer (Wilson's).
1 Do. (De Luc's).
1 Englefield's Barometer.
1 Do. for the Airpump.
1 Gridiron Pendulum.
1 Microscope.

1 Pr. of Metallic Reflectors.
5 Flasks and Screws for weighing Air.
4 Furnaces in tolerable condition.
1 Forge.
1 Mercurial Gasometer.
1 large Iron Mercurial Trough.
2 small do.
115 lb. of Mercury.
1 Copper
1 Tin Gasometers.
2 Stoneware

Glass Apparatus

Sundry Glass bottles and receivers (from modern improvements useless).
8 Dozen Jars for Pneumatic Experiments.

8 Dozen Eudiometers plain and graduated.
5 „ Flasks and Mattrasses of various kinds of sizes.
8 „ Receivers of various kinds.
5 „ Retorts from 4 oz. upwards—plain and graduated.
8 „ do. smaller size.
8 Gas Bottles.
2 Nooth's Apparatus.
1 Woulfe's do.
12 Precipitating Jars.
18 Measuring Glasses.
4 small Porphyry Mortars.
12 Earthenware, Iron, etc. do.
8 Dozen Wine and Beer Glasses of various sorts and sizes.
1 „ Evaporating Dishes, Watch Glasses, etc.
A large quantity of glass tube of various sizes.

A considerable quantity of common apparatus in earthen and stone-ware, such as Crucibles, Muffles, Stands, Tubes, etc. Evaporating Dishes, Basins, etc., etc.
1 Blowpipe Table.
1 Small Still.
12 Oil Lamps, several out of repair.
6 Spirit Lamps.
12 Stands with rings of various sizes to support Retorts.

Certain structural alterations to the building were made in 1828 to meet the views of Dr. Daubeny as expressed in a letter to the Board of Heads of Houses and Proctors.

"Dr. Daubeny being desirous of making certain additions to the Museum, with the view at once of providing better accommodations for his own use than are afforded by the Rooms that have been allotted to the Professor of Chemistry and likewise of improving the present very inconvenient approach to the Lecture Room by attaching to it a spacious Lobby or Vestibule, submits to the consideration of the Board, the accompanying plans drawn by a London Architect, Mr. Parkinson. . . . At all events he engages that the whole shall be completed in a substantial manner, and entirely at his own expense."

A grant of £200 was voted by Convocation to assist him in the execution of repairs and improvements in the apartments appropriated to the Professor under

the Museum. (" Improvement of his habitation in the Vaults of the Museum.") And, in case the wall in front of the premises should sustain damage, it shall be restored at the expense of Dr. Daubeny.

And again on May 28, 1832, it was agreed to raise the floor of the laboratory at a cost of £6 0*s*. 6*d*., but an application from the Professor of Chemistry for alterations to the wine-cellar was rejected.

The cellar of the Chemical Professor was doubtless the one to which Dr. Maskelyne eventually succeeded.[1] Some ugly projections from the basement (constructed at great expense by Dr. Daubeny, who lived there as Chemical Professor) were doomed to be removed when it was proposed to convert the upper part of the building into Examination Schools. (? *circ*. 1860.) (Cox, *Recollections*, p. 85.)

As time went on Daubeny became more and more dissatisfied with the accommodation provided for his chemistry lectures in the basement of the Ashmolean, which was " notoriously unworthy of a great University, being dark, inconvenient and confined." In 1848, or twenty-six years after his election to the chair, he determined to erect a new lecture-room and laboratory opposite Magdalen College. The new Daubeny Laboratory, the oldest of the College Laboratories in Oxford, served as the principal Chemical Laboratory in the University until 1854, when Daubeny's increasing duties at the Botanic Garden compelled him to resign his Chemical Professorship.

In the Laboratory at the Ashmolean he was succeeded by Professor Story-Maskelyne, who gave in-

[1] Some workmen were employed to make some alteration to a wall, when one of them drove his pick through into a small room that had evidently not seen the light of day for generations. They enlarged the aperture, and, on entering, found some bottles that appeared to them of extreme antiquity. Very naturally they tasted the contents and speculated on the possible origin of the long-forgotten hoard. When eventually the discovery was reported to Maskelyne, then at the Mineralogical Department at the British Museum, he became strangely excited and exclaimed, "They have broken into my cellar, the stupid idiots. If they had only looked at the other side they would have seen my new oak door." But what probably rankled in his mind was the thought that his own gin had impaired their clear vision.

struction in chemical analysis; but the new Professor of Chemistry, Dr. Brodie, had no separate laboratory of his own. "He was perpetually agitating for the rapid completion and fitting up of his department. He seems to have given the Delegacy some trouble; and, though it declared "he cannot have priority over the other Professors," he secured it nevertheless. In 1855 he was demanding £600 for additional accommodation, and in 1858 the Delegacy informed Council that, though £1,650 had been spent on chemistry fittings, the Professor still required more. In the same year he gave his first course of lectures in the new Museum, though the gas was not yet laid on, the doors and windows were still unpainted, and the central court was unroofed and unpaved." (Vernon, *Oxford Museum*, pp. 61–2.)

Professor Brodie's laboratory was the remarkable pseudo-gothic building, imitated from the Abbot's Kitchen at Glastonbury, which, with a few small rooms, was described by Sir Henry Acland as being the most complete and largest scientific department in the New Museum. 'There can be no more successful adaptation of an ancient example to modern wants, inasmuch as no more convenient nor more airy laboratory could be contrived, and certainly no bolder or more picturesque design.' Many chemists who have had to work in it have held other views. For over forty years they strove within its gloomy cavern with dust and draughts, while it 'absurdly and fantastically yielded its bed to the crucible, and its blast to the furnace.' In 1902 it was cut in half by a dividing floor. It is, however, no part of our plan to describe the later developments of the natural sciences at Oxford. Dr. and Mrs. Vernon, in their *History of the Oxford Museum*, have done them full justice up to date, 1909, and the time has not yet come for a history of the most recent laboratories.

Other colleges, stimulated by Dr. Daubeny's example, built chemical laboratories. At Christ Church the School of Anatomy was refitted as a Chemical Laboratory in 1868, Balliol under the Hall in 1877, Queen's College in 1900, and Jesus College in 1907.

An account of Dr. Daubeny's lectures, both at the

Ashmolean and at the Botanic Garden, and a list of the members of the University who attended them, with notes on their successes in after-life, have already been published in full in the *History of the Daubeny Laboratory*, printed at Oxford in 1904. Daubeny's views on the *Importance of the Study of Chemistry as a Branch of Education for all Classes* have again been given to the world by Sir Ray Lankester as a contribution to the recent discussion on the "Neglect of Science"[1]: the war but emphasised their truth. With this testimony to the modernity of his outlook it is doubtful whether he should rightly have any place in a history of *Early* Science in Oxford.

[1] *Science and Education.* (8vo. London, 1916.)

DR. JOHN WALL.
From Jewitt, *Ceramic Art.*
See p. 57.

APPENDIX

EARLY CHEMICAL APPARATUS IN THE DAUBENY LABORATORY

The serial numbers correspond to the numbers of the pieces of apparatus figured in the plates

APPARATUS FOR THE PRODUCTION AND APPLICATION OF HEAT

1. The French "fourneau à revérbère." **c. 1818.**

Known in Germany as Becher's Furnace. Thénard, *Traité de Chimie*, Pl. vii, 1818.

2. Cooper's Tube Furnace. **c. 1828.**

For the Analysis of Organic Bodies. Combustions were effected in glass tubes coated with a spiral wrapping of copper foil. Gray, *Operative Chemist*, p. 295, fig. 178, 1828.

2a. Combustion Tube of Berlin Porcelain.

For use with Cooper's Tube Furnace.

3. Newman's Blowpipe. **1816.**

Designed to obviate the difficulty of blowing with the mouth. It was used with compressed gases as the first oxy-hydrogen blowpipe.

4. Gurney's Oxy-hydrogen Blowpipe. **1823.**

Cf. Gray, *Operative Chemist*, p. 103, fig. 64.

DISTILLATION

Retorts

5. Retort of Berlin Porcelain, with loose head.

The head can be fixed with wire and cement, for the preparation of Ammonia, &c.

Griffin, *Chemical Handicraft*.

6. Retorts of Yellow-glazed Stoneware. **c. 1828.**

a. Plain.

b, *c*. Tubulated.

"For dephlegmating oil of vitriol, distilling ether, and many other such occasions, the retorts may be made of the substance of which the pots, &c., commonly called stoneware, are formed.

"They may be obtained at the stone manufactories, at an expense but little exceeding that of glass; and they afford by their durability a great saving compared to glass, where much business is done."

Gray, *Operative Chemist*, p. 274, 1828.

7. Retort of Green Glass, tubulated.

"For ordinary purposes, retorts of green glass are used, either placed in baths, or coated and used in a naked fire; but for some purposes flint glass retorts are obliged to be used." Gray, *Operative Chemist*, p. 274, 1828.

"In consequence of the excellence and present cheapness of the Retorts made of hard white German and Bohemian glass, those of green glass have been omitted from the Catalogue." Griffin, *Chemical Handicraft*, No. 1805.

8. Retorts of French Fireclay.

a. Plain.

b. With short tubulure.

c. With long tubulure.

"Cornues en grès vernis de la fabrique d'Orléans." Griffin, *Chemical Handicraft*, No. 1834.

9. Pear-shaped Bodies of Clear Glass, with ∽-shaped tubular Receivers of thick glass.

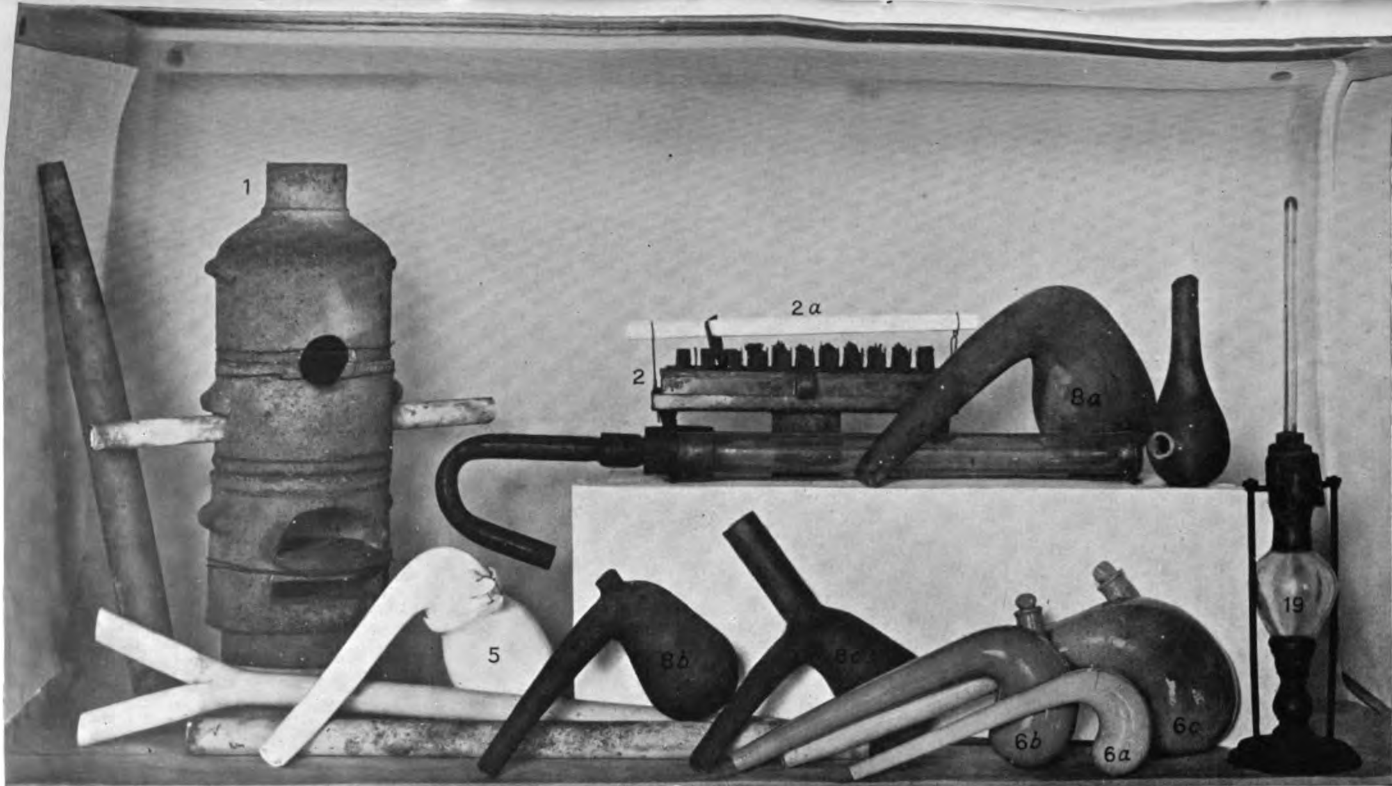
RECEIVERS AND ADAPTERS.

10. ∽-shaped tubular Receivers of thick glass.

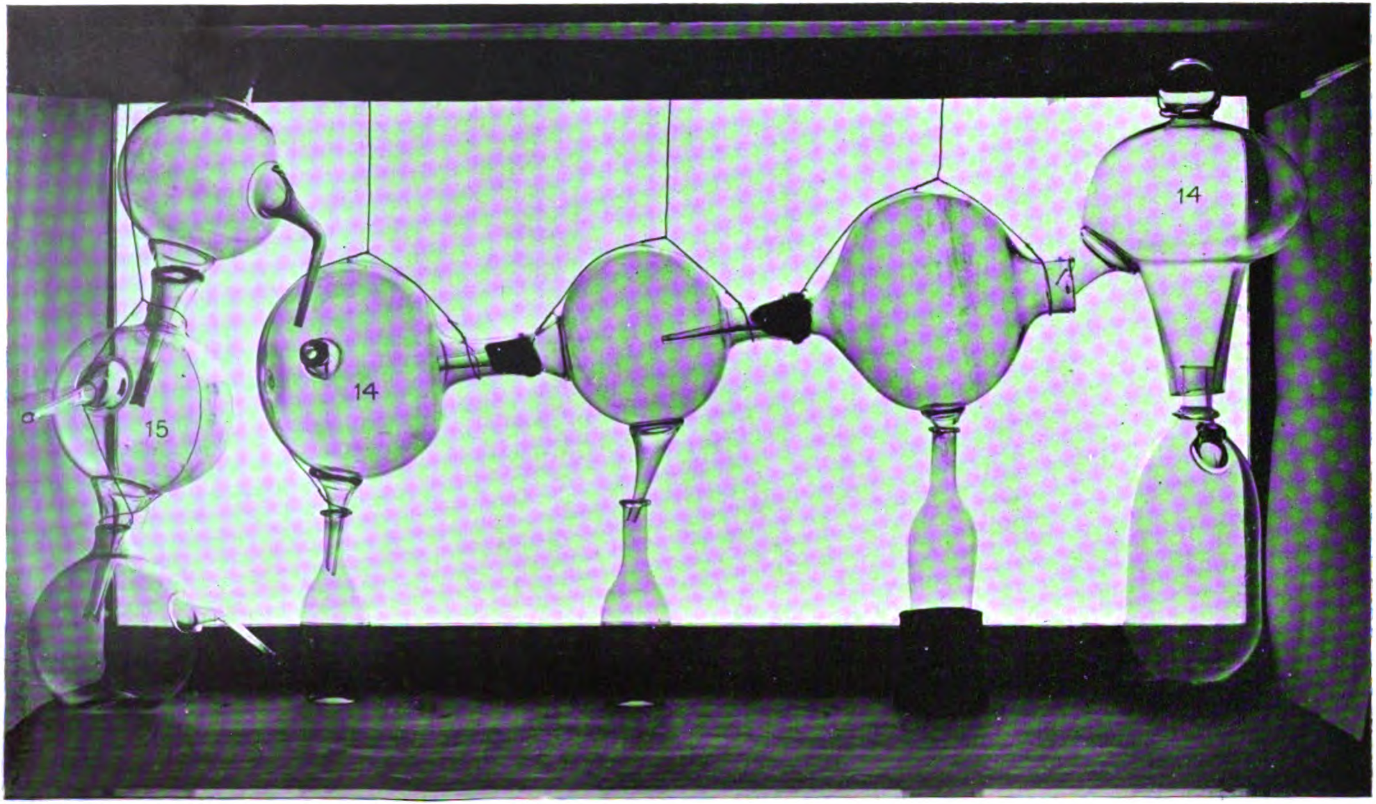
11. Globular Receivers.

12. Adapter.

"In some simple distillations it is necessary to interpose an adapter between the retort and the receiver.

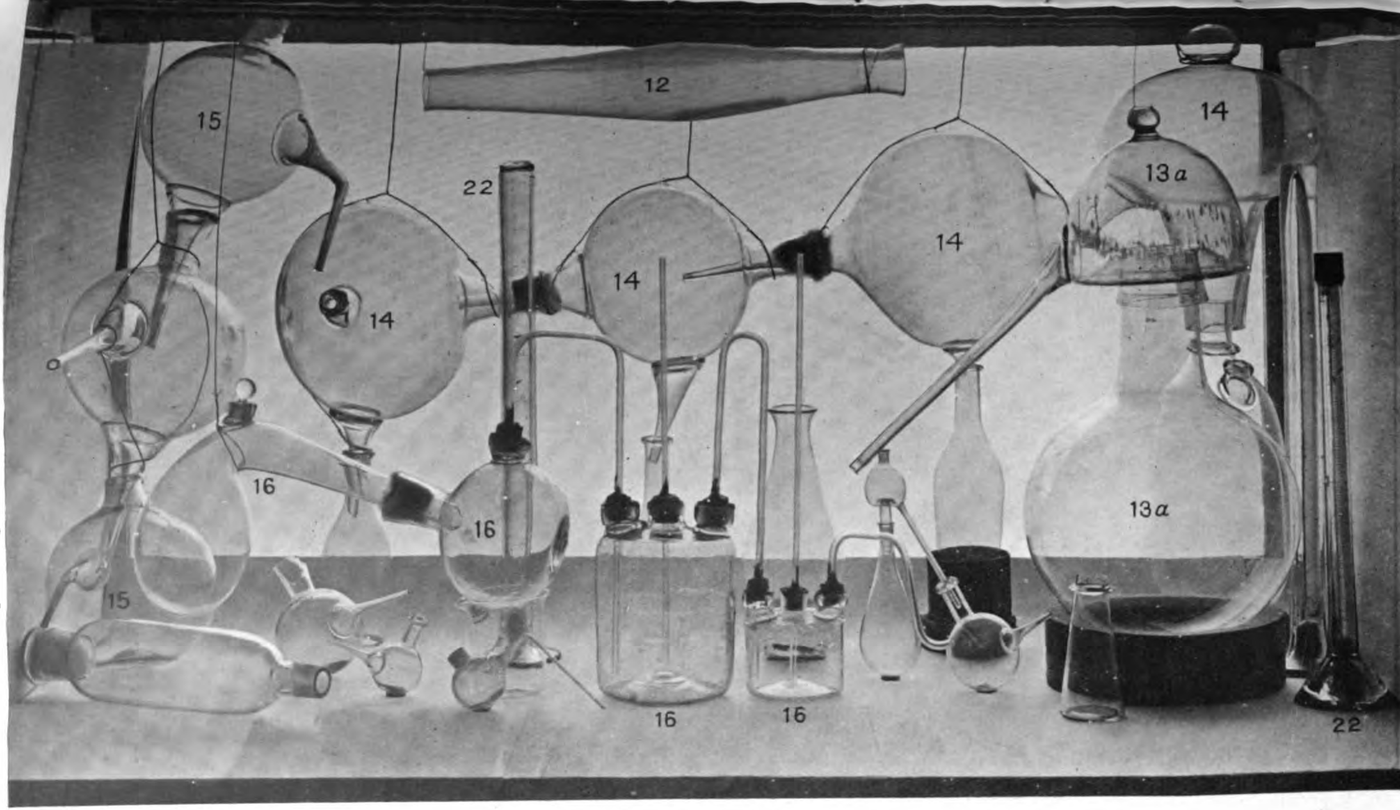


THE DAUBENY APPARATUS (1).

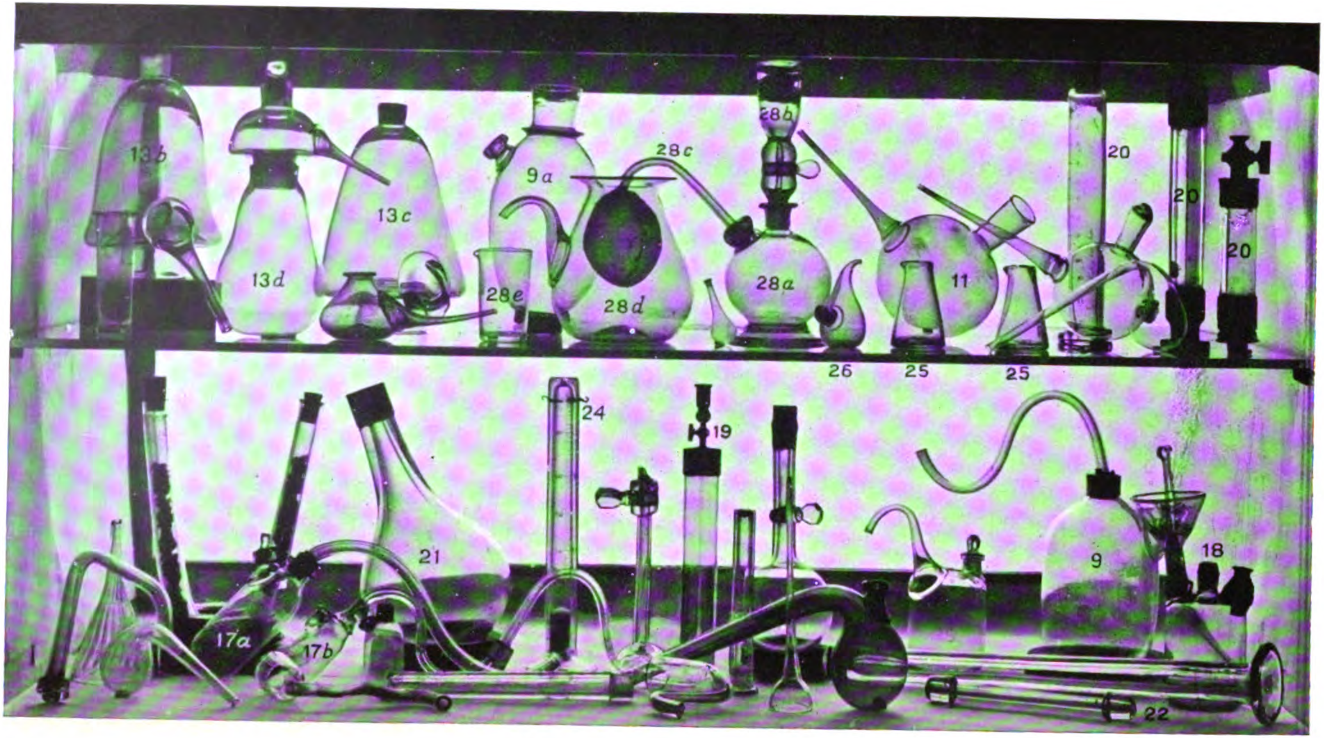


The Hydra.

APPARATUS FOR FRACTIONAL DISTILLATION.



THE DAUBENY APPARATUS (3).



THE DAUBENY APPARATUS (4).

This may serve two different purposes; either to separate two products of different degrees of volatility or to remove the receiver to a greater distance from the furnace, that it may be less heated." Lavoisier, *Elements of Chemistry, Kerr's Translation*, p. 464, 1798.

Alembics

13. Alembics.

a. Head with knob.
b, *c*. Heads with ground stoppers.
d. Head and body, complete.

"Les Alambics de verre sont formés de deux parties, de la cucurbite et du chapiteau. Ils s'emploient ordinairement au bain de sable." Thénard, *Traité de Chimie*, 1818.

"The capital, both of the cucurbit and alembic, has a furrow or trench intended for conveying the condensed liquor into the beak, by which it runs out.

"As in almost all distillations, expansive vapours are produced, which might burst the vessels, we are under the necessity of having a small hole in the balloon or recipient through which these may find vent; hence, in this way of distilling, all the products which are permanently aeriform are entirely lost, and even such as difficultly lose that state have not sufficient space to condense in the balloon; this apparatus is not, therefore, proper for experiments of investigation, and can only be admitted in the ordinary operations of the laboratory or in pharmacy." Lavoisier, *Elements of Chemistry, Kerr's Translation*, p. 462, 1798.

14. Apparatus for Fractional Distillation.

The body provided with a tubulure at the side and a head is followed by three double-necked and quilled receivers fitted one to another in a horizontal series. The distillate is received in the three flasks placed under the receivers. Receivers of this type were described by Peter Woulfe in the *Philosophical Transactions* for 1767 for condensing vapours of nitric acid.

15. Apparatus for Fractional Distillation, known as the 'Hydra.'

Similar to the last, but the recipients are arranged vertically.

16. Compound Distillatory Apparatus of Hassenfratz.

"This apparatus 'is calculated for the most complicated distillations, and may be simplified or extended according to circumstances.' It consists of a tubulated glass retort, a tubulated balloon or recipient, and two or three bottles with three necks; the farthest neck of the last bottle is connected with a jar in a pneumato-chemical apparatus. 'The juncture between the retort and the recipient must be luted with fat lute, covered over with slips of linen, spread with lime and white of egg; all the other junctures are to be secured by a lute made of wax and rosin melted together.'" Lavoisier, *Elements of Chemistry, Kerr's Translation*, p. 468, 1798.

The glass tubes in the middle necks of the bottles were suggested to Lavoisier by Mr. Hassenfratz as a means of avoiding the disaster occasioned by the water in the cistern of the pneumato-chemical apparatus rushing back into the last bottle whenever a small diminution in the heat of the furnace occurs.

APPARATUS FOR THE PREPARATION AND EXAMINATION OF GASES

17. Dr. Priestley's Apparatus for collecting the elastic fluids which are evolved when metals dissolve in acids with effervescence.

The chief inconvenience of this apparatus is that, in many cases, effervescence begins before we have time to cork the bottle properly, and some gas escapes, by which we are prevented from ascertaining the quantity disengaged with rigorous exactness.

18. Lavoisier's Apparatus for Metallic Dissolutions.

"To remedy this, Lavoisier at first used a bottle with two necks, into one of which the glass funnel is luted so as to prevent any air escaping; a glass rod is fitted

with emery to the funnel, so as to serve the purpose of a stopper. Pl. vii, fig. 3." Lavoisier, *Elements of Chemistry*, *Kerr's Translation*, p. 476, 1793.

19-20. Apparatus for Class Experiments with Gases.

21. Detonating Bottle of very stout glass.

22. Glass Cylinders of stout glass, with funnel mouths.

23. Graduated Gas Tubes.

24. Eudiometers.

"The glass of which some of these early forms of detonating tubes is made is extremely thick to enable them to withstand the explosion; but 'the difficulty of preparing and annealing the instrument is such that it is rare to find one that remains sound for any length of time. It sometimes happens that, after an instrument has been made for months, it suddenly explodes without being touched.'" Griffin, *Chemical Handicraft*, No. 2342.

APPARATUS USED FOR ANALYSIS

25. Test Glasses.

a. Conical shape, thick glass. Broader at base than at mouth.

b. Conical shape without stem. Griffin, *Chemical Handicraft*, Shape No. 2412.

c. Clark's conical pattern with stem. Griffin, *Chemical Handicraft*, Shape No. 2410.

26. Dropping Bottle.

For acidimetric or alkalimetric operations.

27. Marsh's Arsenic Test Apparatus.

A tube with two bulbs is fitted with a brass stopcock and jet and is supported upon a mahogany stand.

28. Sir H. Davy's Apparatus for estimating the quantity of calcium carbonate in soils. 1814.

a. Bottle for receiving the soil.

b. Funnel containing muriatic acid, furnished with a stopcock.

c. Tube connected with a flaccid bladder.

d. Bottle for containing the bladder—filled with water.

e. Graduated measure.

When the stopeock is turned, the acid flows into *a*, and acts upon the soil; the elastic fluid generated passes through *c* into the bladder, and displaces a quantity of water in *d* equal to it in bulk, and this water flows through the tube into the graduated measure, and gives by its volume the indication of the proportion of carbonic acid disengaged from the soil; for every ounce measure of which two grains of carbonate of lime may be estimated. *Elements of Agricultural Chemistry*, 1814, p. 167, fig. 15.

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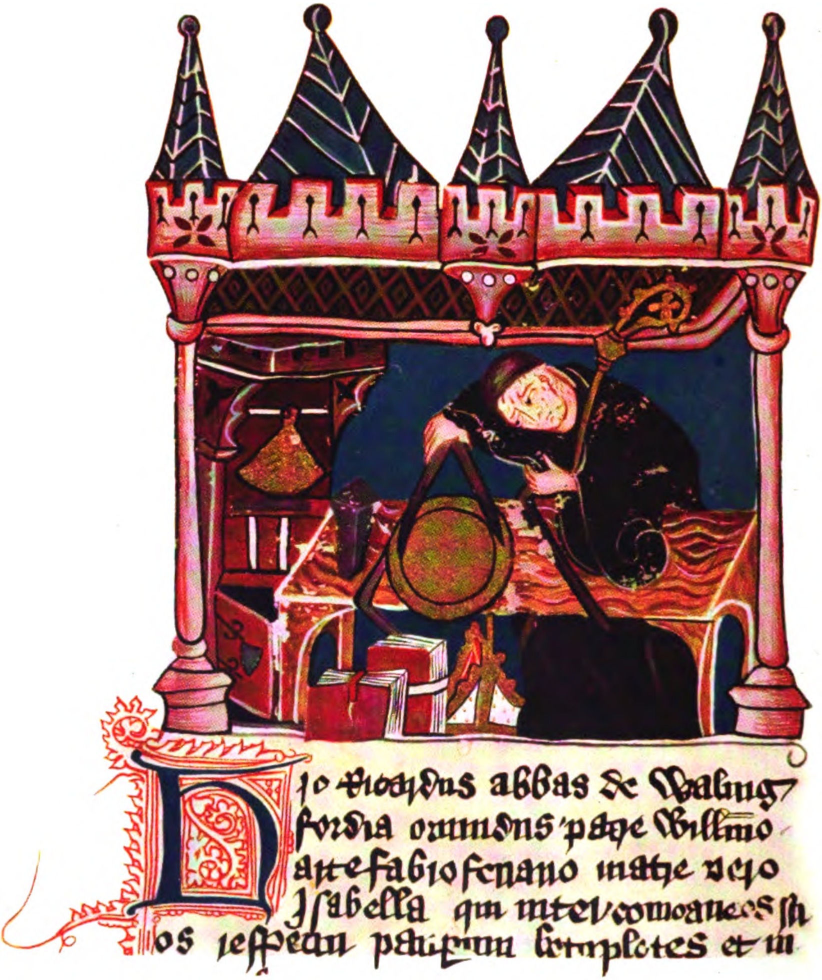

RICHARD OF WALLINGFORD, c. 1326

The earliest representation of a member of the Merton School engaged in making his own instruments. On the bench are anvil, square and hammer. A quadrant is hanging in the cupboard.

EARLY SCIENCE IN OXFORD

PART II—MATHEMATICS

BY

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MAGDALEN COLLEGE, OXFORD

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The Bokes Verdicte.

To pleaſe or diſpleaſe ſure I am,
But not of one ſorte, to euery man
To pleaſe the beſte ſorte woulde I faine
The frowarde diſpleaſe ſhall I certaine.
Yet wiſhe I will, though not with hope,
All eares and mouthes to pleaſe or ſtoppe.

RECORDE, *Grounde of Artes*, 1570.

INTRODUCTORY

The following notes on some Mathematicians and their Instruments have gradually accumulated around a list of the few Mathematical Instruments and other exhibits that were collected in Oxford and shown in the Bodleian Library in the summer of 1919. To raise these notes into a History of Mathematical Studies and Schools in Oxford would defeat the end we have in view, viz. to draw attention to such material objects of value as still remain to us, with a view to their better preservation, and to reviving the memory of the clever men who really helped science forward by the invention of practical methods, and by the cunning of their craftsmanship. At the same time it must be remembered that the term 'mathematical instruments' was formerly used to describe the apparatus employed in various arts and sciences, such as physics, astronomy, surveying, mensuration, &c., in all of which applied mathematics have a part. These will be described under their modern categories.

Of old mathematical instruments in the narrower sense there are now very, very few in Oxford: perhaps some Wise Men have taken them to sea in a bowl.

> If the bowl had been stronger,
> My tale had been longer.

Of first-rate importance are the achievements of the compelling genius of the two Fellows of All Souls, Robert Recorde and Christopher Wren; the instruments of Edmund Gunter of Christ Church; the evidence of the technical skill of Rowley, Bird, Allen, and others; and a unique example of the work of Oughtred, which is also by far the earliest example of a Slide Rule in the world. In the frontispiece we have the clue to the secret of success of the early members of the Merton School. *They made their own instruments*, and thereby acquired that practical knowledge without which no science can give a good education.

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EARLY SCIENCE IN OXFORD

PART II—MATHEMATICS

NOTES ON EARLY MATHEMATICIANS

CONCERNING the teaching and practice of Mathematics in early Oxford, or indeed in England generally during the Dark Ages, very little can be known, though the introduction of the art of Geometry is no doubt rightly referred to Saxon culture.

> The clerk Euclyde on this wyse hit fonde
> Thys craft of gemetry yn Egypte londe
> Yn Egypte he tawghte hit ful wyde
> Yn dyvers londe on every syde.
>
> Mony erys afterwarde y vnders tonde
> Gher that the craft com ynto thys .londe
> Thys craft com ynto England, as y ghow say,
> Yn tyme of good kyng Adelstones day.[1]

To the modern English schoolboy Geometry has become so completely an abstract science, and it is taught him so divorced from its practical applications, that the actual meaning of the word does not come easily to him. But in the beginning it was not so, the first geometers were expert at measuring and planning. Gower (1390), the first to use the word in English, defines Geometrie as that 'through which a man hath the sleight of length, of brede, of depth, of height'.[2] The cunning of the geometer lay in the designing and skilful application of surveying instruments.

ATHELSTAN (925-40), anxious to promote the welfare of his people, would have encouraged any foreign geometers made known to him through his international

[1] Bib. Reg. Mus. Brit. 17A I, f. 2^{b}–3.
[2] *Confessio Amantis*, iii. 90.

alliances: one of his sisters being married to Otto the Great, another to Hugh, father of Hugh Capet. Two centuries later an Englishman, ADELARD OF BATH, endeavoured to carry out the policy initiated by King Alfred of making exotic wisdom accessible to his fellow-countrymen, and among other translations rendered the Elements of Euclid from Arabic into Latin (A.D. 1120).[1] In 1186 Gerard of Cremona made a second and apparently independent translation from another copy of the Moorish text.

Later on, however, Adelard's translation fell into the hands of ~~GIOVANNI~~ CAMPANUS of Novara, who produced it as his own, *c.* 1260, and perhaps thereby so commended himself to Pope Urban IV that he obtained the post of chaplain (1261–81) within a few months. Campanus's claim to originality has been disputed by Tiraboschi and by the author of the article *Geometry* in the Penny Cyclopaedia.[2] Campanus also worked up Ptolemy's views into a *Theorica Planetarum* which became widely known. It was one of the compulsory books prescribed for candidates for the master's degree at the university of Vienna in 1389. His version of Euclid was adopted as the basis of the first printed editions.[3]

In the year 1180 a certain DANIEL OF MORLEY is mentioned as residing in Oxford. He was probably one of the first mathematicians connected with our University, and wishing to pursue his studies at first hand, he migrated to Paris, as a first step towards journeying to Arabia. But discovering *en route* that there was a flourishing mathematical school established at Toledo, he made his way thither, and in due course returned as a teacher.[4]

In the opening years of the thirteenth century the entire system of calculation of the Western nations began to change. Sums had hitherto been worked out according to the system of the Arithmetic of Boethius, or on the fingers. In 1202 LEONARD OF PISA perceiving the

[1] Early MSS. of Adelard's works are not uncommon. We have at least two in the Bodleian; *MS. Selden Arch.* B. 29 and *MS. Bodley* 3623.

[2] Halliwell, *Rara Mathematica*, p. 57, and Cantor, *Gesch. Math.*, ii, p. 102.

[3] J. Gow, *Greek Mathematicians*, 1884.

[4] Suter, *Math. auf der Univ. des Mittelalters*, p. 21.

advantage of the Arabian system of numeration with 9 digits and a zero, explained this new method or Algorism[1] in a treatise, the 'Liber Abbaci'. Two circumstances helped to spread the new symbols: the wholesale translation of Arabian scientific books by the Jews employed by Frederick II in 1230, and the increasing circulation of popular almanacs in which Arabic numerals made an early appearance.

Perhaps the most famous of the mathematicians of this time was the Yorkshireman, John of Holywood, also called Halifax or more usually Sacrobosco. He was educated in Oxford but afterwards migrated to Paris where he acquired a very great reputation as a teacher. From him many Oxford students obtained their mathematical and astronomical knowledge. The books by which he is best known are the

De algorithmo.
De sphera, 1256. Prescribed for candidates for the bachelor's degree at Prague as late as 1384.
De computo ecclesiastico.
De astrolabio.

John of Holywood died in 1244.

Another early student who notably helped on the study of mathematics was John of Basingstoke, who was in Oxford at the beginning of the thirteenth century and died in 1252. He had travelled in the pursuit of knowledge and spent a considerable time in Athens, profiting by the instruction in Greek that he received from the learned daughter of the Archbishop. To their joint efforts we owe several translations of Greek books into Latin. Judging by the standard of the science of that day, the work of these early translators is to be highly valued. The world had not yet learnt that the books of the ancients are but a sorry substitute for the study of Nature herself. The dominance of Authority was irremissible, and there was no incentive to further creative effort.

[1] Algorism = Lat. *algorismus* from Arab. *al-Khowārazmī*, surname of the mathematician Abu Ja'far Mohammed Ben Musa who flourished early in the ninth century, and through the translation of whose book on Algebra the Arabic numerals became generally known in Europe.

The practical art of measuring and planning presupposes the use of instruments. But of the simpler tools, of ancient compasses, squares or rules, there are now none extant. Of the more elaborate instruments the very few that have survived from the Middle Ages and are known to have been used by Oxford mathematicians will be described under the heads of Astronomy and Surveying. For any further information we are obliged to rely on such descriptions of instruments as we find in manuscripts, and on the results obtained by the mathematicians themselves. Since our knowledge therefore is almost wholly derived from inference it follows that this portion of the subject must be incomplete.

A student in the faculty of Arts in a mediaeval university such as Oxford was expected to devote his first four years to the subjects of the trivium and the next three to those of the quadrivium. On the satisfactory completion of his training in the 'trivial' subjects of Grammar, Logic, and Rhetoric, and while still but a schoolboy, he was granted the bachelor's degree and was deemed to be sufficiently advanced to grapple with the mathematical and scientific studies of the quadrivium, Arithmetic, Music, Geometry, Astronomy.

During the twelfth and first half of the thirteenth century these scientific studies included as much science as was to be read in the pages of Boethius (*c.* 470–525), Cassiodorus (468–568), and Isidore of Seville (560–636), 'with superstitious absurdities about the virtues of certain numbers and figures thrown in'.[1] The living truths of science were therefore presented through the medium of a system at the very least some six hundred years old.

By Arithmetic was meant at that time the study of the proportions of numbers; and particularly of ratio, proportion, fractions, and polygonal numbers. It did not include the art of practical calculation, so that the abacus, the instrument upon which calculations were then generally performed, was not required for the academic curriculum.[2] For the modicum of Geometry that was necessary, Boethius and Gerbert were read.

[1] Hallam, *Literature*, p. 3.

[2] W. W. Rouse Ball, *Hist. of Mathematics at Cambridge*, from which we have derived much information.

They supplied the enunciations of the first book of Euclid and a few selected propositions from Books III and IV. Some practical applications to the determination of areas were usually added in the form of notes. But even this was too advanced for most students, and few if any of the residents at Oxford had mastered more than the definitions and the enunciations of the first five propositions of Euclid Book I.[1]

Geometry is stated to have also included a few notions of Geography extracted from Cassiodorus and Isidore.

The diagrams in geometrical manuscripts are evidence of the use of drawing instruments of the simpler kind. The straight edge or 'rewle', the square, and some sort of compasses for drawing circles would all have been borrowed from the craftsman. But whether the mathematician's set of instruments included compasses with equal legs, or with unequal legs, like ***Y***, or whether beam compasses were used, or whether circles were more frequently drawn by means of a pin and a bit of string, we do not know.

All the above methods had long been in use in Europe. Both Greeks and Romans were familiar with the ordinary straight-limbed compasses, and the latter people made use of proportional compasses, in which the proportion of the long to the short limbs was fixed.

About 1100 we hear of compasses of iron composed of two parts, a larger and a smaller with straight or curved legs.[2]

Our academic Astronomy was founded on Ptolemy, but to the ecclesiastically minded a living interest was imparted by rules for finding the movable festivals of the Church. To the greater number of students there was incentive and fascination in the prospect of mastering the lucrative art of the Astrologer. The general experience of early medical men was that it paid to know mathematics; and even among the Arabian physicians the numbers who are known to have been eminent as mathematicians is remarkable.[3] The close relation-

[1] Prop. 5, now known as the *pons asinorum*, was known to Roger Bacon as *Elefuga* or *fuga miserorum*. *Opus Tertium*, cap. vi.

[2] *Theophilus*, iii, c. 16.

[3] Wüstenfeld, *Gesch. arab. Aerzte*, Göttingen, 1840; Suter, *Mathematiker der Araber*, *Abh. Gesch. math. Wiss.*, 1900.

ship between mathematical and medical sciences in quite early times was due to various causes, partly to a general belief in the influence of the stars on human health, which required skill in the use of mathematical instruments as part of the equipment of a qualified medical man; to faith in the potency of certain numbers, particularly 3 and 7, and in geometric squares and figures such as mystic trigrams, pentacles, &c.; to the belief of many physicians that drugs had to be compounded so as to bring out their *dynamidiae* (this no doubt led a physician like Arnaldo de Villa nova (1235–*c.* 1313) to the study of mathematics); and finally to the study of optics, especially by oculists, first among the Arabs and later among the thirteenth-century Western scholars.

By 1250 many Arabian works had been translated into Latin, with the result that Euclid, Archimedes, Apollonius in addition to Ptolemy were henceforward accessible to the student.

In the fourteenth century the study of the mathematical sciences flourished greatly in Oxford, and especially in MERTON COLLEGE. The achievements of some of the leading members of this school will be recounted in the sections that are more particularly devoted to astronomers. The writings[1] of RICHARD OF WALLINGFORD, MAUDITH, SIMON BREDON, JOHN ASHENDEN, WILLIAM REDE and others, show them to have been one and all practical mathematicians of no mean order, as well as scholars of wide attainments and qualified for the highest posts in Church and State. The results of their labours have never been printed, and but few ever look at their manuscripts: thus it is that we have no cognizance of work produced during a century in which Oxford could boast more Mathematicians than any country in Europe. This fact alone should point to the desirability of a critical re-examination of their writings. So little was known of these pioneers, that Montucla, the eminent mathematical historian, placed

[1] Richard of Wallingford, *c.* 1326.	*De sinibus demonstrativis.* *De sinibus et arcubus.*
John Maudith, *c.* 1340.	*De chorda et arcu recto et verso et umbris.*
Simon Bredon, *c.* 1380.	*Tabulae chordarum.* *Calculationes chordarum.*

Bradwardine, one of the foremost of them, at the beginning of the sixteenth century, and the late Professor Miall has recently declared that 'before the seventeenth century no Englishman was recognized as the founder of a science school'.

For the deciphering of papyri and for many ramifications of archaeological research, helpers and money have been readily forthcoming, but records of the scientific work of scholars of a period in which English science was pre-eminent are still awaiting an editor.

Their mathematical instruments, like those of Richard of Wallingford, would have included a straight edge, a square, and a pair of compasses, and would often have been little if any better than blacksmith's tools. In the frontispiece to this book Richard is represented in his workshop measuring the diameter of a circle with such painful exactitude that blood-red beads of perspiration are streaming down his face.[1]

The tractates of one member of the Merton School were published in the early days of the printing press, possibly in consequence of the high office to which he succeeded. THOMAS BRADWARDINE is generally recognized as the greatest English mathematician of the fourteenth century. He was born at Hartfield near Chichester, *c.* 1290. He was educated at Merton College and is probably to be identified with a Franciscan who in 1325 is known to have become Proctor. He lectured on theology, philosophy, and mathematics with such distinction that he was called Doctor Profundus. His chief mathematical works were probably written while he was residing in Oxford as a lecturer: they comprise the following:

Tractatus de Proportionibus,[2] Paris, 1495.
Arithmetica speculativa, Paris, 1502.
Geometria speculativa, Paris, 1511, 1530.
De Quadratu circuli, Paris, 1495.

His life as a mathematician probably came to an end about 1335, when he was called away from Oxford to take part in the political life of the Church. There is an interesting summary in the Dictionary of National

[1] MS. Cotton, Claud. E. iv, part 2, f. 201.
[2] See also MS. Digby 76, ff. 110–120, and MS. Digby 228.

Biography of his public acts, including his trip with the victorious English armies to Calais and Cressy. He died Archbishop of Canterbury in 1349.[1]

Manuscripts that actually belonged to him are contained in that precious volume in the Bodleian Library, known as Digby MS. 176 which, according to the inscription on the back of the first folio, was the book of Master W. Rede, Bishop of Chichester, who purchased a part of it from the executors of Thomas Bradwardine, and wrote a part himself.

Several other early teachers of eminence of this period might be mentioned, but we have no evidence that they essentially contributed to the experimental or instrumental side of the subject. An early instance of an intercollegiate lecture system is that which obtained in the time of JOHN CHYLMARK, a man of considerable mathematical attainments, who lectured in the schools belonging to Exeter College in 1386. It has been pointed out that these lectures would probably have been open to members of Merton College as well. Chylmark's *Tractatus de Motu* was written out by John Buxhale in the fifteenth century but this and his other works have never been published.[2]

Of fifteenth-century mathematics there is little to be said.

Between 1449 and 1463 the only mathematical subjects required for the master's degree in the quadrivium were the first two books of Euclid and the astronomy of Ptolemy, either in the original or in a commentary.[3]

It was not until the sixteenth century that Oxford men again figure prominently by having notably advanced the study of pure mathematics, but in almost every case their success seems to have been promoted by a change of environment which stimulated a fuller growth of their powers. The earlier of these:

CUTHBERT TONSTALL, *b.* Hackforth, Yorks., 1474,

[1] Chaucer cited Bradwardine as an authority on the question

> Whether that Gods worthy forweting
> Straineth me needly for to doe a thing.
> *Nun Priest's Tale.*

[2] *D.N.B.* and MS. Bodl. 676.

[3] *Register* quoted in the Life of Bishop Smyth, the founder of Brasenose College, by Ralph Churton, Oxford, 1800 (Hallam).

d. 1559, 'had entered at Balliol College, but finding the philosophers dominant in the university, he migrated to King's Hall, Cambridge'—our Cambridge authority then explains that 'His action only meant that he could continue his studies better at Cambridge than at Oxford'.[1] He subsequently went to Padua where he read works by Regiomontanus and Pacioli. His arithmetic *De arte supputandi* was the best of its time and is particularly valuable as containing illustrations of the mediaeval processes of computation. It was printed by Pynson in the year in which he became Bishop of London, 1522;[2] and again in Paris in 1529 and 1538. Special type for cancelled digits is used in this book.

At Cambridge it has been noted[1] that Tonstall and Recorde were the only two English mathematicians of any note of the first half of the sixteenth century; both migrated from Oxford. They are the first mathematicians at Cambridge of whose lives and works any details are known, and are therefore to be regarded as the founders of what has been the most brilliantly successful mathematical school in the world.

The old learning of the Moors in Spain, cherished, transmuted, and increased by the astronomer-mathematicians of the Merton School of the fourteenth century, was taken by these men and planted in the virgin soil of Cambridge, where it has grown and flourished into a mighty tree.

Of the two men the one with the more commanding genius and educational foresight was ROBERT RECORDE (1510?–1558), Fellow of All Souls College, 1531, and Doctor of Medicine of Cambridge, 1545.

His eloquence as a lecturer used to be rewarded by the applause of his audience, and is still remembered in the pages of Bale, who was in a position to have heard accounts at first-hand. As treated by him, the fundamental rules of Arithmetic became clearer than they had ever been before. He also taught Astrology, explained Cosmography, illustrated Geometry and Music. He was particularly strong on the subject of mining for gold, silver, copper, tin, lead, and other metals, probably

[1] Ball, *History of Mathematics at Cambridge*, p. 11.
[2] De Morgan, *Arithmetical Books*; J. Leslie, *Philosophy of Arithmetic*, 1820; Cooper, *Athenae Cantab.*, i, p. 198, 1858.

as the result of early experience in a Welsh mining district.

Recorde's modest works would not fill a quarter of one of the massive tomes of the great schoolmen, yet they are more of a landmark in the history of the advancement of learning than those more pretentious volumes. He was the first to introduce Algebra into

The pathway to
KNOWLEDG, CONTAI-
NING THE FIRST PRIN-
ciples of Geometrie, as they
may moste aptly be applied un-
to practise, bothe for use of
instrumentes Geome-
tricall, and astrono-
micall and
also for projection of plattes in everye
kinde, and therfore much ne-
cessary for all sortes of
men.

Geometries verdicte

All fresshe fine wittes by me are filed,
All grosse dull wittes wishe me exiled:
Thoughe no mannes witte reiect will I,
Yet as they be, I wyll them trye.

THE SECOND ENGLISH GEOMETRY, 1551.

England,[1] and both his Arithmetic and his Geometry[2] enjoyed a wide popularity.

[1] The earliest use of the word Algebra occurs in 1551 in Recorde's *Pathway of Knowledge*, 'Also the rule of false position, with dyvers examples not onely vulgar, but some appertayning to the rule of Algebra'.

[2] The first Euclid in the English language was made in 1570 by Sir Henry Billingsley, assisted by John Dee. G. B. Halsted, *Note on the first English Euclid*, *Amer. J. Math.*, ii, 1879.

Recorde's works passed through many editions.

His Arithmetic, the *Ground of Arts*, was printed in 1542, 1561, 1582, 1607, 1623, 1636, 1646, 1652, 1658, 1663. It was based on manuscripts entitled *De origine artium* and *Arithmeticae principia*.

The Geometry, the *Pathway to Knowledge*, appeared in 1551, 1574, 1602. It was printed from manuscripts entitled *Geometriae semita* and *Theoremata Geometriae*.

The Algebra, the *Whetstone of Witte*, was printed in 1557, from his *Secunda pars Arithmeticae*.

The *Urinal of Physic*, printed in 1548, 1567, 1599, 1651, was his *Vrinale physices* and *De judiciis urinarum*.

The *Castle of Knowledge*, printed in 1556, 1596.

Bale has preserved the names of several other works, of which some may not have been completed. They include—*Anatomia; Cosmographiae Isagoge;* Translation of *Euclid; De arte mensurandi; De arte faciendi horologium; De usu globorum; De peregrinatione hominis* and *De origine nationum; De statu temporum* and *Mutationes regnorum; Imago reipublicae verae; De effectibus creaturarum; De auriculari confessione; De negotio Eucharistiae.* Copies of the last two of which were among Recorde's own books, when they were examined by Bale.

Recorde was also the first to insist on the advantage of pure mathematics as a training for the mind. The *Preface to the pathwaie to Knowledge, containying the first principles of Geometrie*, 1551, begins with these words:

'Excuse me gentle reader if oughte be amisse, straung paths ar not trodē al truly at the first: the way muste needes be comberous, wher none hathe gone before. Where no man hathe geven light, lighte is it to offend, but when the light is shewed ones, light is it to amende. If my light may so light some other, to espie and mark my faultes, I wish it may so lighten thē, that they may voide offence. Of staggeringe and stomblinge, and unconstaunt turmoilinge: often offending, and seldome amending, such vices to eschewe, and their fine wittes to shew that they may winne the praise, and I to hold the candle, whilest they their glorious works with eloquence sette forth, so cunning invented, so finely indited, that my bokes maie seme worthie to occupie no roome. For neither is mi wit so finelie filed, nother mi learning so largely lettred, nother yet my laiser so quiet an un cōbered, that I maie per-

The whetstone of witte,

whiche is the seconde parte of Arithmetike: containyng thextraction of Rootes: The Cossike practise, with the rule of *Equation*: and the woorkes of *Surde Nombers*.

Though many stones doe beare greate price,
The whetstone is for exersice
As neadefull, and in woorke as straunge
Dulle thinges and harde it will so chaunge,
And make them sharpe, to right good use
All artesmen knowe, thei can not chuse,
But use his helpe: yet as men see,
Noe sharpenesse semeth in it to bee.
The grounde of artes did brede this stone:
His use is greate, and moare then one.
Here if you list your wittes to whette,
Moche sharpenesse therby shall you gette.
Dulle wittes hereby doe greately mende,
Sharpe wittes are fined to their fulle ende.
Now prove, and praise, as you doe finde,
And to your self be not unkinde.

¶ These Bookes are to bee solde, at the Weste doore of Poules, by Jhon Kyngstone.

THE FIRST ENGLISH ALGEBRA, 1557.

form iustlie so learned a laboure or accordinglie to accomplishe so haulte an enforcement. . . .'

A short verse tersely sums up the case for the study of geometry.

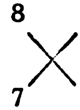
Geometries verdicte.

All fresshe fine wittes by me are filed,
All grosse dull wittes wishe me exiled:
Thoughe no mannes witte reiect will I,
Yet as they be, I wyll them trye.

Although his name is now remembered by few, some of the methods he introduced have become part of our everyday usage.

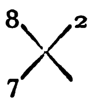
The great point about his Arithmetic, or *Grounde of Artes*, as he called it, was that it was written in English, and that each rule was explained by a method so simple that 'euerie child can do it'. The instruction is given in the form of a dialogue between Master and Pupil. Recorde's way of doing multiplication resembled that already described by Grammateus in 1518. A large sign of multiplication was used, and in a position very different from that customary nowadays. The Master's teaching begins as follows:

'First set your digits one over the other right, then from the uppermost downward, and from the neathermoste upward drawe straight lines, so that they make a crosse, commonly called St. Andrew's crosse as you see heere.



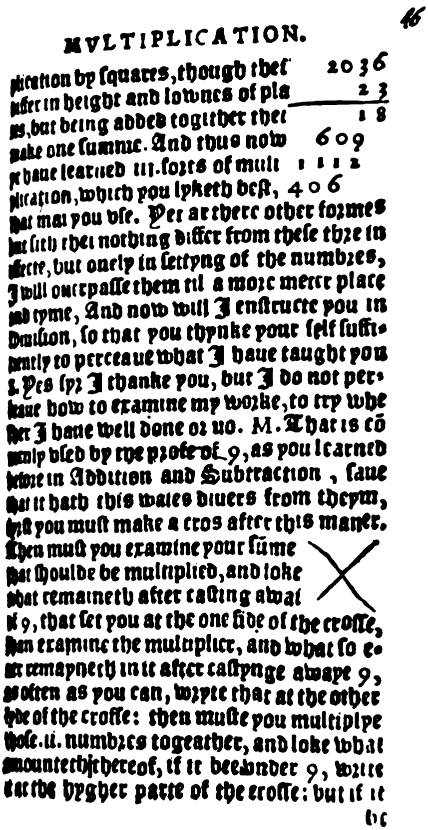
'Then looke howe many eche of them lacketh of 10, and wryte that against eche of them, at the ende of the lines, and that is called y^e Differences: as yf I would know how manye are 7 times 8, I must write those digits thus.

'Then do I looke how muche 8 doothe differ from 10, and I finde it to bee 2, that 2 do I write at the right hande of 8 at the ende of the line, thus.'



The Master's further instructions, as printed on page 103 of the 1596 edition of the *Ground of Arts*, are facsimiled on page 19.

The setting up of so large a cross evidently bothered the compositor of the first edition of Recorde's arithmetic, and the result was a very one-sided and wobbly

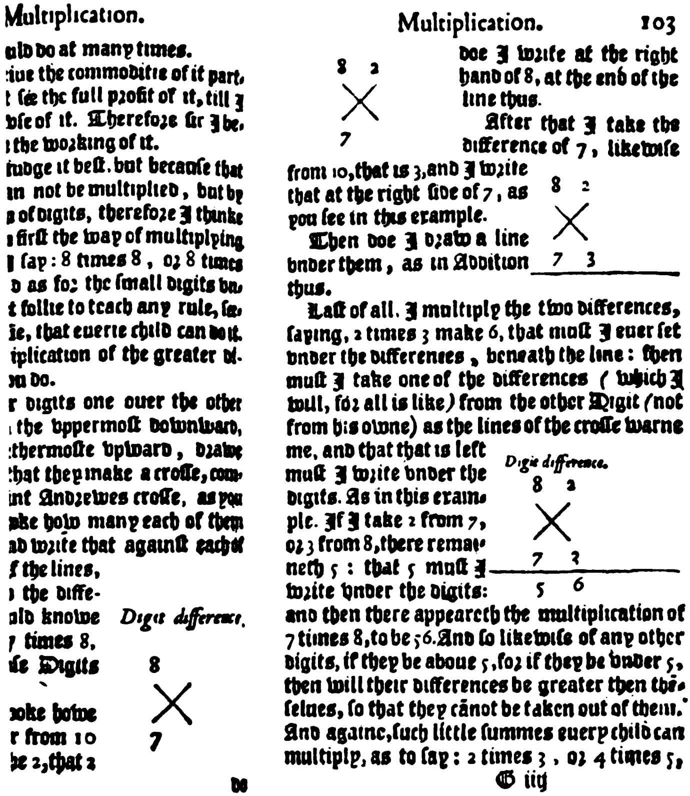


MVLTIPLICATION. 46

plication by squares, though they 2036
differ in height and lownes of pla 23
ces, but being added togither they 18
make one summe. And thus now 609
ye haue learned iii. sortes of multi 1112
plication, which you lyketh best, 406
that mai you vse. Yet are there other formes
but sith they nothing differ from these thre in
effecte, but onely in settyng of the numbres,
I will ouerpasse them til a more meter place
and tyme, And now will I enstructe you in
Diuision, so that you thynke your self suffi-
ciently to perceaue what I haue taught you
S. Yes syr I thanke you, but I do not per-
ceaue how to examine my worke, to try whe
ther I haue well done or no. M. That is cō
monly vsed by the profe of 9, as you learned
before in Addition and Subtraction, saue
that it hath this waies diuers from theym,
that you must make a cros after this maner.
Then must you examine your sūme
that shoulde be multiplied, and loke
what remaineth after casting awai
of 9, that set you at the one side of the crosse,
then examine the multiplier, and what so e-
uer remayneth in it after castynge awaye 9,
as often as you can, wryte that at the other
side of the crosse: then muste you multiplye
those .ii. numbres togeather, and loke what
amounteth thereof, if it bee vnder 9, wryte
at the hygher parte of the crosse: but if it
be

THE SIGN OF MULTIPLICATION [1542].
Grounde of Artes, p. 46.

affair: but in the later editions the crosses became better formed, smaller, and more like our modern sign of multiplication, the use of which was an improvement advocated by Oughtred in 1631.



Multiplication.

uld do at many times.
:iue the commoditie of it part,
t see the full profit of it, till I
vse of it. Therefore sir I be,
i the working of it.
iudge it best. but because that
in not be multiplied, but by
s of digits, therefore I thinke
s first the way of multiplying
I say: 8 times 8, or 8 times
d as for the small digits vn,
t follie to teach any rule, se,
ie, that euerie child can do it.
iplication of the greater di.
ou do.
r digits one ouer the other
, the vppermost downward,
:thermoste vpward, drawe
:hat they make a crosse, com,
int Andrewes crosse, as you
ake how many each of them
nd write that against each of
f the lines,
i the diffe-
uld knowe *Digit difference.*
7 times 8,
se Digits 8
oke howe
r from 10 7
be 2, that 2

do

Multiplication. 103

8 2

7

doe I write at the right hand of 8, at the end of the line thus.

After that I take the difference of 7, likewise from 10, that is 3, and I write that at the right side of 7, as you see in this example.

8 2

7 3

Then doe I draw a line vnder them, as in Addition thus.

Last of all, I multiply the two differences, saying, 2 times 3 make 6, that must I euer set vnder the differences, beneath the line: then must I take one of the differences (which I will, for all is like) from the other Digit (not from his owne) as the lines of the crosse warne me, and that that is left must I write vnder the digits. As in this example. If I take 2 from 7, or 3 from 8, there remaineth 5: that 5 must I write vnder the digits:

Digit difference.

8 2

7 3

5 6

and then there appeareth the multiplication of 7 times 8, to be 56. And so likewise of any other digits, if they be aboue 5, for if they be vnder 5, then will their differences be greater then themselues, so that they cannot be taken out of them. And againe, such little summes euery child can multiply, as to say: 2 times 3, or 4 times 5,

G iij

THE SIGN OF MULTIPLICATION, 1596.
Ground of Arts, p. 103.

This method of multiplication seems to suggest a lack of familiarity with the multiplication table above 5 times. After lengthy explanations, the concluding question and answer are particularly ingenuous.

'*Scholar*. Syr, what is the chiefe use of Multiplication.
Mayster. The use of it is greater than you can yet understand.'

Euclid, replying to a similar questioner, said to a slave 'Give him sixpence, since he must needs gain by what he learns'.

B—2

He selected the symbol = as a sign of equality, because no two things could be more equal than two parallel lines.

> Howbeit, for easie alteratiō of *equations*. I will propounde a fewe exāples, bicause the extraction of their rootes, maie the more aptly bee wroughte. And to auoide the tediouse repetition of these woordes : is equalle to : I will sette as I doe often in woorke vse, a paire of paralleles, or Gemowe lines of one lengthe, thus: =====, bicause noe. 2. thynges, can be moare equalle. And now marke these nombers.

ze

1. 14.ze. —+— .15.ϙ ===== 71.ϙ.

2. 20.ze. ——— .18.ϙ ===== .102.ϙ.

3. 26.ʒ —+— 10ze ===== 9.ʒ —— 10ze —+— 213.ϙ.

SIGN OF EQUALITY: EARLIEST PRINTED USE, 1557.
Whetstone of Witte, Sign. Ff. j.

The + and − symbols occur for the first time in print in John Widmann's Arithmetic, printed at Leipzig in 1489, but did not come into general use in England before the publication of Recorde's *Whetstone* in 1557.

> 'There be other ·2· signes in often use of which the first is made thus —+— and betokeneth more: the other is thus made —— and betokeneth lesse.'[1]

Such is a brief account of one of our earliest and greatest mathematicians. Recorde's claim to have cleared

[1] The pages of the *Whetstone* are not numbered. The quotation is from the back of signature S, ii.

It has been suggested that the symbols + and − arose from the marks chalked on chests of merchandise in German warehouses, to denote excess or defect from some standard weight. They appeared again in a work by Stifel in 1544. As far as the other common signs are concerned, the sign of division ÷, used by J. H. Rahn in 1659, was introduced into England by John Pell in 1668 (Cajori, *Hist. of Mathematics*, p. 151); to Napier we owe the decimal point; to Oughtred the mark of proportion : :, as well the smaller ×.

a path for others, who might attain to greater fame than himself, is amply justified. His arithmetic, the most popular that England had known, went through thirty editions. But it is characteristic of the fickleness with which Fame distributes her favour, that although Recorde was a Fellow of All Souls, yet two years back his name was quite unknown there, and not one of his numerous printed books is in the College Library. On the other hand Fortune, no less fickle, has ordained that materials for reconstructing the catalogue of Recorde's private library should have survived; and having regard to the rarity of such early records, and the bearing of the books on the history of Early Oxford Science, no apology is necessary for printing it here. It would be interesting to trace the whereabouts of his manuscripts of the early Astronomers of the Merton School.

ALBERICUS ANGLUS. De Eucharistia.
ARDERNE, J. Practica chirurgie.
ASHENDON, J. De significatione conjunctionum, beg. 'Sicut dicit Ptolemeus'.
BATECUMBE, GUILH. De fabrica et usu sphere concave.
De sphaera concava.
BRACTON, R. DE. De legibus Anglie.
BREDON, SIMON. Arithmetica theorica.
Expositio in quaedam capita Almagesti et Ptolemei.
DONAKAMEN. Versus vaticinales de Britannia.
EGLYNE, GEFFREDUS V. GALFRIDUS. Prophecia.
FITZHERBERT, ANTONY. Epitome legum Anglie.
De agricultura [and another].
Indices librorum.
FORTESCUE, SIR JOHN. De laudibus legum Anglie.
De politica administratione ac legibus Anglie.
De natura legis naturae. 2 vols.
GILDAS. De sexto cognoscendo carmina xxx *et* xl carmina.
GIRALDUS CAMBRENSIS. Topographia Hiberniae.
De expugnatione Hiberniae.
De mirabilibus Hiberniae.
Distinctiones ejusdem.
Itinerarium Britannie.
Vaticinalis historia.
De purgatorio patricii.
GLANVYLE, R. De legibus Anglie.

HEREFORD, ROGER OF. Theorica planetarum.
HOLBROKE, J. Tabulae astronomicae cum canones.
HOVEDEN, ROGER. Historia Anglorum post Bedam.
KAERLION, LUDOVIC, M.D., fl. 1480. De eclipsium calculatione.
KYLLYNGWORTH, J. Arithmeticum opus.
LYTELTON. De legibus Anglie.
MAUDVITH, J. Tabulae astronomicae.
MAYDESTON, RICHARD. Tractatus in J. de Northampton.
Anulum philosophicum et canones.
MERLIN. De honoribus.
Dicta in septimo ca.
Alia prophecia sub nomine Bede, 22 carmina.
Prophecia de quodam sexto.
MERLINUS SYLVESTRIS. Prophecia.
MERLINUS AMBROSIUS. Epitaphium sexti regis.
MURIS, J. DE. Prophecia ut homines iusticiam sequantur.
NORTHAMPTON, J. DE, fl. 1310. Anulus philosophicus.
NORTON, THOMAS. De transmutatione metallorum.
RECORDE, R. De auriculari confessione.
De negotio Eucharistie [and others].
REDE, WM., Bp. Chichester. Tabulae astronomicae et canones in easdem.
SCRIBA, ROB. Carmina vaticinalia.
SCROPE, RIC. Invectiva in regem Henricum IV.
SOMER, J. Tertium Calendarii, 1380.
STATHAM, NIC. Epitome actionum municipalium.
TOLLEY, DAVID. Themata Homeri.
UPTON, NIC. De vera nobilitate.
WALLINGFORD, RIC. Albion.
Exafrenon de iudiciis astronomicis.
WALTER, J. Tabulae ascensiorum universalium. (Perhaps in same vol. with Holbroke.)
Author unknown. Vaticinium temp. regis Ioannis.
Chronicon, 1065–1285.

With the departure of Recorde to enlighten the sister University, Oxford mathematics sank to a low ebb. So low that in 1554 some patriotic Oxonians, regretting the manner in which scientific studies were being treated, offered a member of St. John's College, Cambridge, John Dee (1527–1608), a stipend to come and lecture on mathematics in Oxford; but he declined the invitation. It was a pity. He would have been a most attractive figure, with his long white beard, his longer gown with hanging sleeves, without which he never appeared abroad.

He would have drawn the whole university to his lecture-room with his amusing stories of intercourse with the angels, with his stage-trick of making Aristophanes Scarabaeus mount up to the top of a College dining-hall, his experiments on the transmutation of metals, his magic crystal (now in the British Museum).

H S ex dono Th: Digges authoris

ALÆ SEV SCALÆ
Mathematicæ, quibus viſibilium remotiſsima Cœlorum Theatra conſcendi, & Planetarum omnium itinera nouis & inauditis Methodis explorari: tùm huius portentoſi Syderis in Mundi Boreali plaga inſolito fulgore coruſcantis, Diſtantia, & Magnitudo immenſa, Situſq; protinùs tremendus indagari, Deiq; ſtupendum oſtentum, Terricolis expoſitum, cognoſci liquidiſsimè poſsit.

THOMA DIGGESEO, CANTIENSI,
Stemmatis Generoſi,
Authore.

¶ *Londini. Anno Domini.*
1573.

TITLE-PAGE OF SIR H. S[AVILE'S] COPY OF DIGGES' 'ALAE'.

But if Dee would not do anything for Oxford, his pupil THOMAS DIGGES of Queens' College, Cambridge, did

notable service. For he edited and printed the works of his father LEONARD DIGGES of University College, Oxford, thus preserving to us the record of the inventor or maker of the first efficient telescopes. Thomas Digges was the first English author to describe the theodolite.[1] His handwriting may be seen in a presentation copy of his book of Mathematical Tables, the *Alae*, in the Bodleian Library.

It has been said that all the English mathematical contemporaries of Recorde and Digges were educated at Cambridge. It is, therefore, not surprising that we should have no notes of mathematical instruments of their period at Oxford, while at the sister University Edward Wright, a Norfolk man of Caius College, acquired a great reputation as a constructor of instruments.[2]

And the success of the Cambridge men who followed was as noticeable among those who wrote on the philosophy of Science, as among the mathematicians. We will but mention one who occupies a large place outside the portals of science, but a very small one within. The writings of Francis Bacon (1561–1626) were for the public at large, they increased the respect for Science, but it has been rightly stated that he did not himself make any one single advance in natural knowledge. He was a pupil, not a teacher: he believed that the investigation of natural phenomena and their accurate record would give to man a power in this world which, in his time, was hardly to be conceived. 'What he believed, what he preached, he did not practise.' 'I only sound the clarion but I enter not into the battle.'

When SIR HENRY SAVILE (*b.* 1549, *d.* 1622) became Warden of Merton, he seems to have felt that there was a reproach in this abandonment of science to Cambridge. Accordingly about 1570 he began to give lectures on geometry, which he opened free to all members of the University. He never, however, succeeded in taking his class beyond the eighth proposition, Euclid Book I.

[1] For a description of the Theodelitus, see Digges, *Pantometria*, 1571.

[2] For a detailed description of his 'Coelestial Automaton' *c.* 1620, see *MS. Brit. Mus. Sloan* 651.

'Exolvi per Dei gratiam, domini auditores, promissum; liberavi fidem meam; explicavi pro meo modulo, definitiones, petitiones, communes sententias, et octo priores propositiones Elementorum Euclidis. Hic, annis fessus, cyclos artemque repono.'

Tutorial classes in Trinity College were conducted in more lively fashion by Ralph Kettell (1563–1643). Indeed, the solution to one of his problems is remembered even to this day.

'I will show you', said the lecturer, 'how to inscribe a triangle in a quadrangle. Bring a pig into the quadrangle, and I will sett the colledge dog at him, and he will take the pig by the eare; then come I and take the dog by the tayle, and the hog by the tayle, and so there you have a triangle in a quadrangle; quod erat faciendum' (Aubrey, *Lives*).

The methods of Savile and Kettell probably both bore fruit.

Mathematical instruments were regarded as possessions of value by private owners. At Magdalen, President Bond (1589–1607) bequeathed to his servant George Neighbour both his globes and other mathematical instruments, valued at 40 shillings in all (Macray, *Register*, ii. 180; viii. 23).

A recent historian[1] has suggested that mathematics and astronomy began to assert claims to individual and distinct existence from an amalgam of scientific learning, during the Stewart period. At Oxford, at any rate, these studies had been segregated (to use Sir A. Shipley's word) in the fourteenth century, but during the seventeenth century there occurred a great outburst of scientific inquiry, which was partly the result of the invention of new methods and of innumerable new instruments, by the use of which advance in natural knowledge was immensely facilitated. Early in the century (1614), Napier of Merchiston (1550–1617) had made known his discovery of logarithms, already privately communicated by him to Tycho Brahe in 1594, and tables, the material factor necessary to make the general use of logarithms practicable, were calculated by Henry Briggs[2] and first published in 1617.

[1] Shipley, *The Progress of Science*, *Camb. Hist. Engl. Lit.*, viii.
[2] If Recorde took the signs +, −, and = from Oxford to Cam-

Seven years later, with the aid of the table of logarithms, rules were constructed so as to show the results of logarithmic calculations without calculation. This, the slide rule, which to-day plays a large part in physical and engineering science, was the invention of Edmund Gunter of Christ Church. Decimals were coming into use, and at the close of the century algebra was being written in the notation we still employ, for which Francis Vieta of Paris (1540–1603) has the credit of priority.[1]

Sir Henry Savile, feeling the need of science and of yet more science, founded the Chairs of Geometry and Astronomy in 1619. He offered the former to Henry Briggs (1561–1631) of Cambridge, who had just brought out his logarithmic tables in which decimal notation is used for the first time, by underlining the decimal figures. 23$\underline{12}$ meant 23·12. The decimal point employed by Napier did not come into general use until the beginning of the eighteenth century. Briggs's decimals and mathematical powers were evidently in advance of the times, for there were among the gentry persons who had been at the University themselves, but who kept back their sons in order not 'to have them smutted by the black art' (Wood)—so much did the ignorant distrust the witchery of mathematics.

At his death Savile's foundations were still further helped by a bequest of his valuable Library to the University on conditions stated at the beginning of the original Savile Catalogue in the Bodleian Library.

'A Catalogue indented betweene the Vniversitye and Sr Henrie Savile contayning the names of such bookes as the sayd Sr Henrye Savile hath bequeathed to the Vniversitye for the vse cheifly of the Mathematical-Readers; who may borrowe any of them, putting in a sufficient [Reall][2] caution.'

Mention must be made here of one of Briggs's contemporaries, who, though not a member of this University, appears to have given private tuition in mathematics to many Oxford men.

bridge, Briggs paid us back by importing decimals from St. John's, Cambridge, into Oxford when he became Savilian Professor.

[1] Vieta, *Canon Mathematicus*, 1st edit. 1579, 2nd edit. 1609.

[2] The word *Reall* has been added later.

WILLIAM OUGHTRED (*b.* Eton, 1574; at King's College, 1592; *d.* Albury, Surrey, 1660) received *c.* 1614 one of the earliest copies of Napier's Canon on Logarithms and embodied the discovery in the circular scales or Circles of Proportion of which he wrote an account in 1632. A description of an Oxford example of this unique instrument is given on p. 67. Among his practical improvements to the science were a more extended use of the symbols × and ∷, and contractions for sine, cosine, &c.[1]

Oughtred worked at mathematics in the seclusion of a country vicarage. At Albury he 'gave gratuitous instruction to any who came to him, provided they would learn to write a decent hand'. He complained bitterly of the penury of his wife who always took away his candle after supper, 'whereby many a good notion was lost and many a problem unsolved'; and one of his pupils, who secretly brought him a box of candles, earned his warmest esteem.[2] He is related to have died of joy at the Restoration: but it should be added, by way of excuse, that he was eighty-six years old (De Morgan).

Oughtred's instrumental works included:

The Circles of Proportion, 1632. 2nd edit. with illustrations 1633, 3rd edit. 1660.
The double Horizontal Dial, 1636. 2nd edit. 1652.
Sun-dials by Geometry, 1647.
The Horological Ring, 1653. 2nd edit. 1674.

A mind of a more practical order was that of EDMUND GUNTER of Christ Church, inventor of several instruments, and afterwards Gresham Professor. Born in Herts, in 1581, he was educated at Westminster, and matriculated at Christ Church in Jan. 1599/1600.

An early work, a *New Projection of the Sphere* circulated in manuscript in 1603, gained for him the friendship of the Earl of Bridgewater, William Oughtred,

[1] Oughtred's contractions were *s*, *sco*, *t*, *tco*, *se*, *seco* for sin, cos, tan, cot, sec, cosec.

[2] Pupils of the time had not very exalted use for mathematics. Lord Herbert of Cherbury thought arithmetic and geometry fit to learn for their helpfulness in keeping accounts and in enabling a gentleman to understand fortifications. Lord Herbert was only twelve when he came up to University College in 1595.

Henry Briggs, and other leading mathematicians. Three years after he had taken his B.D. degree and had been presented to the living of St. George's Southwark, he invented the small portable quadrant that is associated with his name (1618). It served as a ready means of finding the hour and azimuth and other useful astronomical and geometrical purposes.[1]

He further effected an improvement in the use of the Cross-staff and showed how to take a back observation by that instrument, whereby the error arising from the eccentricity of the eye is avoided.

Gunter's *Canon Triangulorum; or Table of Artificial Sines and Tangents, to a radius of 100,000,000 parts to each minute of the Quadrant*, 1620, or as we should now say of log, sines, and tangents to seven places of decimals, was the first table of its kind published, and did for sines and tangents what Briggs had done for natural numbers. In these tables Gunter applied to navigation and other branches of mathematics his admirable rule, 'the Gunter', on which were inscribed the logarithmic lines for numbers, sines, and tangents of arches. For this invention he was given full credit by Oughtred, who in his *Circles of Proportion* says: 'the honour of the invention of Logarithms, next to the Lord of Marchiston, and our Mr. Briggs, belongeth to Master Gunter, who exposed their numbers upon a straight line. And what does this new instrument (of mine) called "Circle of Proportion" but only bow and reflect Master Gunter's line or rule?'

When Sir Henry Savile was about to appoint his first Professor of Geometry in Oxford, he sent for Gunter who came 'and brought with him his sector and quadrant, and fell to resolving of triangles and doeing a great many fine things. Said the grave knight, *Doe you call this reading of Geometrie? This is shewing of tricks, man!* and so dismisst him with scorne, and sent for Henry Briggs from Cambridge' (Aubrey's *Life of Savile*).

Gunter was the first to use the terms cosine, cotangent, and cosecant for the sine, tangent, and secant of the complement of an arc. He introduced the useful abbreviation log *a* for the logarithm of *a*. He discovered magnetic variation in 1622. In his capacity as Gresham

[1] See the Appendix to his *Book of the Sector*.

Professor, he drew the lines upon the dials in Whitehall Gardens, and wrote a description of their use at the request of Prince Charles. The dials were destroyed in 1697.

The following works were written by him:

Description and use of the Sector, Cross-staff, and other instruments, 1624.[1] 2nd edit. 1636, 4th edit. 1662, 5th 1673.
Description and use of his Majesties dials in Whitehall Garden, 1624.
Description and use of a portable instrument known by the name of Gunter's Quadrant. Publ. by W. Leybourne, 1685.

After Gunter's death in 1626 his works were reissued and widely circulated by his successor, Samuel Foster, Gresham Professor 1636, who added his own notes on several astronomical instruments.[2]

Geometricall dyalling being a full explication of divers difficulties in the works of learned Mr. S. F. By J. Collins, 1659.
The Workes of E. Gunter, whereunto is now added the further use of the Quadrant. By S. Foster, 1653.
The Works of E. Gunter, 4th edit. to which is added the description of another sector . . . as also, of a Quadrant . . . both invented and written by S. F. 1662 and 1673.
The art of dialling; by a new easie and most speedy way, 1638.
The description and use of the Nocturnal, ? 1685.
Elliptical, or azimuthal horologiography. Publ. G. R. and W. Leybourn, 1654.
Posthuma Fosteri, the description of a Ruler, upon which is inscribed divers scales and the use thereof. Invented and written by Mr. S. F., 1652.
S. F. *Planetary Tables and Theories*, 1645–7. MS. Brit. Mus.

The presence of Gunter, Foster, and others was doubtless the reason that during the first part of the seventeenth century the study of mathematics 'was more cultivated in London than in the Universities'.

At a later period, when Oxford Science was beginning to develop on modern lines, experimentalists were repeatedly hindered by lack of appliances and of the

[1] An interleaved copy with many notes in Gunter's handwriting is in the Bodleian Library 4° Rawl. 180. His drawing of a protractor is figured on p. 120.
[2] Ward, *Lives of the Gresham Professors.*

means for constructing them. A man like the ingenious Mr. Hooke, imbued with the true scientific spirit and skilful in the making of instruments, could readily make discoveries and thus earn a rich reward of fame; but the work of those who had not his technical skill was perforce limited, for scientific workers, however highly trained, must remain helpless without adequate appliances for their researches.

So far as mathematical instruments go, we have only noted the case of FRANCIS POTTER of Trinity College about 1649, who 'invented and made with his owne hands a paire of beame compasses which will divide an inch into a hundred or a thousand parts. At one end of the beame is a roundle, which is divided into 100 equall parts, with a sagitta to turne about it with a handle: this handle turnes a skrew of a very fine thread, and on the back of the saile or beame is a graduation. With these compasses he made quadrants'. He gave John Aubrey a pair of these compasses, which he showed to the Royal Society[1] at their first institution, which they well liked; and Aubrey then presented them as a rarity to his friend Edmund Wyld. 'There are but two of them in the world.'

Potter would seem to have greatly improved upon the beam compasses depicted by Leonardo da Vinci in 1493, which were similarly provided with a screw fine adjustment.

Generally speaking, during the first half of the seventeenth century, 'mathematics were scarce looked upon as Academical studies', and were stigmatized as mechanical. But then a great change occurred: in 1649 a double election was made to the Savilian Chairs. SETH WARD, *b.* 1617, B.A. of Sidney Sussex College 1637, was appointed Astronomy Professor and JOHN WALLIS (1616–1703) Professor of Geometry. These two mathematicians were leading members of the Philosophical Society, and both exerted themselves to revive the study of mathematics at Oxford.

A serious study of modern mathematics now began. Wallis[2] and Barrow helped to explain the analytical geometric methods of Descartes (published in 1637) and

[1] *MS. Aubr.* 6, f. 63 v.
[2] The use of the sign ∞ for infinity is due to Wallis.

the method of indivisibles of Cavalieri. But the new mathematics were not easy, and some of the best brains of the older members of the University were perplexed by them.

Dr. Seth Ward, when President of Trinity College, no doubt feeling the difficulties of making his propositions clear to his scholars, 'did draw his geometricall schemes with black, red, yellow, green, and blew inke to avoid the perplexity of A, B, C, &c.' And Dr. John Pell, 1611–85, 'when he solves a question he straines every nerve about him, and now in his old age it brings him to a loosenesse'.[1]

But clearly the stimulus of the new learning soon began to be felt. Wallis himself contributed a report on an investigation on sound to the Philosophical Transactions, and perhaps suggested further research to Noble of Merton and Pigot of Wadham whose work will be referred to later. Among Wallis's pupils may also be numbered the most distinguished man of Science whom Oxford has ever produced.

CHRISTOPHER WREN was in residence from 1649 to 1657, being a Fellow-commoner of Wadham College, 1649–53, and Fellow of All Souls 1653–61. At the age of twenty-five he was appointed Gresham Professor of Astronomy, and moved into rooms at Gresham College (1657).

As a mathematician Wren excelled in geometrical demonstrations. The principal achievements that may be referred to his earlier Oxford period include a scheme for the graphical construction of solar and lunar eclipses, and occultations of stars. The method, clearly explained and illustrated by him, was referred to with approval by Flamsteed, but was not published until many years later.[2]

About 1656 he solved a problem proposed by Pascal to the geometers of England, and retorted by sending a challenge to the French savants—one which had originally been issued by Kepler, and which Wren had himself solved. This challenge was not answered.[3]

Four tracts on the cycloid were communicated by him

[1] Aubrey, *Lives*.
[2] In Sir Jonas Moore's *System of Mathematics*, p. 533, in 1681.
[3] (*D. N. B.*)

to John Wallis, who published them in 1658.[1] One of these was Kepler's problem, which Wren had solved by means of a cycloid. It is stated that his demonstrations of the cycloid are of such a nature as to be proper subjects for the differential calculus: but Wren's solutions preceded by many years the publication of Newton's fluxions, or the equivalent method of Leibnitz.

Through Hooke[2] we know about a beautiful geometrical method for one of the steps in the graphical determination of a comet's path. It is much to be wished that more of Wren's geometrical demonstrations had been recorded in fuller detail: the few that have come down to us quite justify Newton's high opinion of Wren, naming him with John Wallis and Christian Huyghens as 'beyond comparison the leading geometers of this age'.[3]

Wren seems to have taken very little pains to secure for himself the merit of his various inventions, and it was widely believed that the secretary to the Royal Society, Henry Oldenburg, was in the habit of communicating Wren's inventions to friends in Germany, who passed them off for their own.[4]

With Wren this brief sketch of the earliest periods of mathematical studies in Oxford may fittingly be brought to a close.

In subsequent chapters we hope to allude to a few of the other works and inventions of the great architect in the varied fields of Astronomy, Geodesy, Meteorology, Physiology, and Mechanics. He died in 1723 at a period when the simpler types of mathematical instruments had attained their modern form and were often constructed with a skill that is lacking nowadays. For although a higher grade of accuracy has been reached by the use of modern dividing engines and machine tools, yet the old masters were often our superiors in hand-work, and almost always so in the artistic finish of their manufactures.

When Nathaniel Bliss became Savilian Professor of Geometry (1742-65) he put out a Notice of Six

[1] John Wallis, *Mathematical Works*, i. 533, 1658.

[2] Hooke, *Cometa*, 1678, in his *Posthumous Works*, p. 104. A Diagram and text is printed in Elmes's *Life of Sir Christopher Wren*, App. p. 60, 1823.

[3] Newton, *Principia*, p. 20.

[4] *D. N. B.*

SIR CHRISTOPHER WREN, P.R.S.
by Sir P. Lely

Courses of Lectures to be given at his House in New College Lane.

Course IV dealt with Plain Trigonometry 'To which will be added the *Practical* Geometry, comprehending the Description and Use of *Instruments*, and the Manner of measuring *Heights*, *Distances*, *Surfaces*, and *Solids*'.

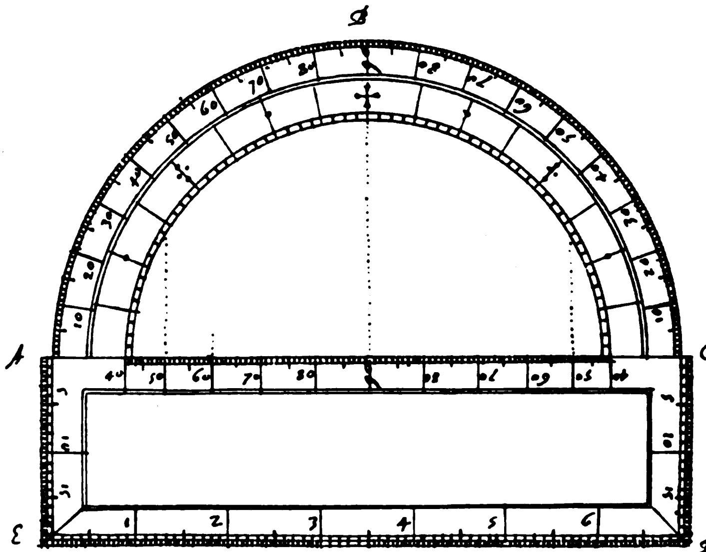
It was proposed that the Number of Scholars in the Course should not be less than *Six* or more than *Ten*; to whom the Professor would read three Days in a Week, and not less than an Hour each Day, explaining the Propositions, and illustrating them with Examples, and such Observations, as the Matter required, *until the Company apprehended and understood it.*

It was computed that the Course would require about *three Months*; and any *Gentleman* might go through any *one* or *all* of the Courses as he pleased, paying two Guineas at the Beginning of the Course and half a Guinea more for every Month the Course continued longer than *three.*

Mathematics had begun to take a serious turn!

We have not found in the University Collections many instruments which were actually designed or made by Oxford men. Perhaps there is something in the atmosphere of the University that is not altogether favourable to the establishment of a school of craftsmanship or to the appreciative preservation of its works, though such technical assistance as the skilled instrument-maker can supply is most necessary to the efficient development of learning, research, and observation. This has been realized at Cambridge, where an attempt to meet a similar deficiency has been made recently by the formation of the Cambridge Scientific Instrument Company.

'Without mathematical instruments', wrote Roger Bacon, 'no science can be mastered', and no one felt the need of them more keenly than he.



* Or he may divide the meridian of his Chart by the Line of a protractor such as is commonly used by Surveyors of land and is here represented by ABCDE wherein the outward part of the Semicircle ABC is divided equally into 180 gr. the inward not equally into 16 Rumbs and every Rumbe subdivided into 4. The lines CD, DE, EA

Drawing of a Scale and Protractor invented by Edmund Gunter, with part of the original description in his handwriting.

From Gunter, *Sector* 1624 Bodl. 4° Rawl. 180.

DESCRIPTIVE CATALOGUE OF

EARLY MATHEMATICAL INSTRUMENTS BELONGING TO THE UNIVERSITY AND COLLEGES OF OXFORD

Illustrated by a comparative account of some of the oldest instruments in the collections of the Royal Society, of Mr. Lewis Evans, and in other collections.

We cannot do better than preface our list of old Mathematical Instruments in Oxford with an extract from the first general Course or Collection of Mathematical Instruments that was attempted in the English language. This comes the more appropriately, because it was published in 1723 in the lifetime of Lord Orrery, to whom the most valuable of the oldest Oxford instruments had belonged.

'There seems, then, but little wanting to Mathematicks, considered as a Science: If there be any Defect, 'tis when considered as an Art. I mean, Mathematicks appears more accessible, as well as more extensive, on the Side of their Theory than on that of their Practice. Not that the latter has been less laboured by Authors than the former, but because a sufficient Regard does not seem to have been had to the *Instruments*, whereon it wholly depends.

'Mathematical Instruments are the Means by which those Sciences are rendered useful in the Affairs of Life. By their Assistance it is, that subtile and abstract Speculation is reduced into Act. They connect, as it were, the Theory to the Practice, and turn what was bare Contemplation, to the most substantial Uses. The Knowledge of these is the Knowledge of Practical Mathematicks: so that the Descriptions and Uses of Mathematical Instruments, make, perhaps, one of the

most serviceable Branches of Learning in the World. The way then to render the Knowledge of Mathematicks general and diffusive is by making that of Mathematical Instruments so.'[1]

At the same time it must be remembered that in all ages some mathematicians have contemned the use of instruments. With Plato they have held that geometry, for example, should not be materialized, that it should not by instrumental or other aid be brought down from the region of eternal and incorporeal ideas. So thought John Ward in 1707. Yet even Plato is stated to have had recourse to an instrument when he wished to solve the Delian problem, and John Ward recommended the handiwork of John Rowley.

The Cista Mathematica

The great Mathematical Instrument Box of the University is now at the end of the Bodleian Picture Gallery next the Savilian Tower. It rests on a low stand, and invites speculation as to whether at the time of its making all the mathematical learning in the University was to be compressed within its eleven feet of capacity. Its stout sides of 1½-inch oak planking, dove-tailed ends, hinges and fastenings of wrought iron look strong, yet without the burglar-proof appearance of the many-bolted lock of Sir T. Bodley's strong-box.

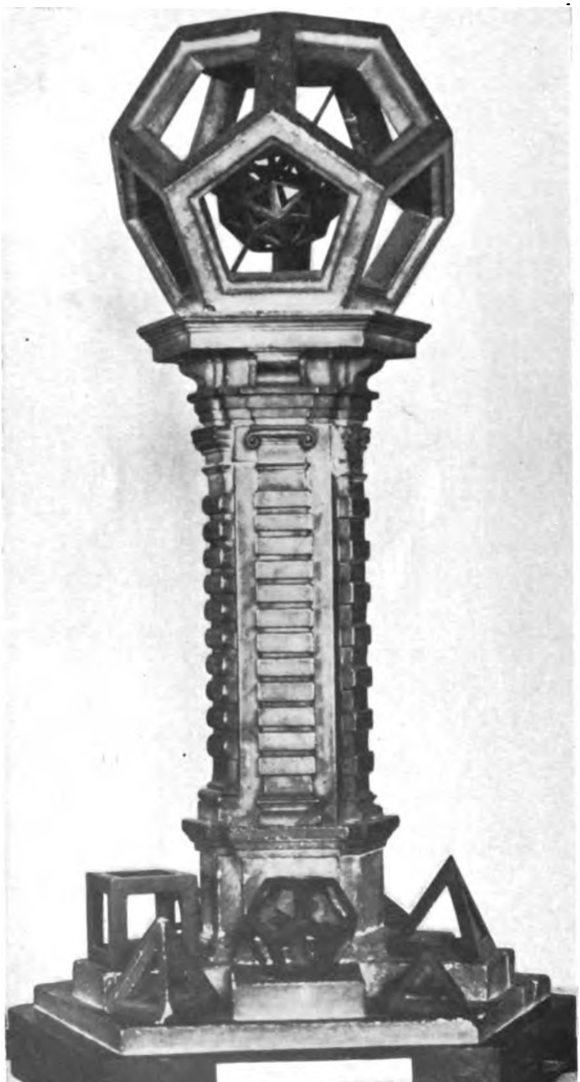
The chest is now empty: but the triple locks show that it was not always intended to be so. The three locks open with different keys. Only when the *Clavis ad mediam seram Cistae math:* with a ward to the right was turned in the lock between those keys which shot the bolts of the locks on either side, would the Cista disclose its secrets.

It is not improbable that the Cista was provided after the death of Sir Henry Savile in 1621, and before the list of the Savilian apparatus was printed in 1697.

[1] Preface by Edmund Stone to his translation and improved edition of the work on *Mathematical Instruments* by M. Bion, Chief Instrument Maker to the French King.

NO. 34. SPHERES

CISTA MATHEMATICA



NO. 29. MATHEMATICAL MODELS

Mathematical Models

29. Model representing the five orders of Architecture. c. 1690–1700.

Picture Gallery, Bodleian Library.

Pilasters carved in alabaster, 22 inches in height, bearing Geometric Solids.

Uffenbach,[1] under date 19 August 1710, alludes to this column as standing on a table in a window of the Library, and notes a few brass 'measuring instruments', well made and perforated, which lay about it.

I imagine that our modern Professors of Mathematics would either smile or protest, if asked to give instruction on this model. Not so their predecessor, David Gregory, who in 1700 put forward a scheme for mathematical teaching in Oxford, which was designed to be 'most beneficial to youth (especially of the Nobility and Gentry),' and was even submitted to Pepys for criticism. In this scheme it was suggested that subjoined to the *practical geometry* may be a lecture of *fortification* . . . or, of the *five orders of pillars and pilasters*.[2] It was such a lecture that this model was undoubtedly intended to illustrate.

Then, the best architects building in the classical style knew and observed the rules of good proportion, and studied the comparative strength of vaults and arches. Now a sense of good proportion has vanished, and our architects in trouble consult an engineer.

Conic Sections. Before 1697.

Formerly in Savile Collection, now missing.

'14. Conus in parabolam, hyperbolam & ellipsin dissectus.'
Cat. libr. manuscr. 1697, p. 302.

Models for demonstrating Propositions of Euclid. Before 1697.

Formerly in Savile Collection, now missing.

'16. Elementorum Euclidis Schemata ligno efformata.'
Cat. libr. manuscr. 1697, p. 302.

[1] Uffenbach, *Reisen*, iii, p. 100.
[2] *Collectanea*, p. 322, *Oxf. Hist. Soc.*

Geometric Solids

In the larger books on architecture and perspective published during the second half of the sixteenth century, it had become customary to treat of the geometrical solids, which were doubtless made in skeleton form to facilitate studies in perspective.

As examples we may cite the *Livre de Perspective* by Cousin, printed in Paris in 1560, which was illustrated with a large engraving of the five regular geometric solids grouped about an architectural doorway; also the frontispiece to Barozzi, *Regola delli cinque ordini d'architettura*, Libro secondo, Venetia, 1596. A few earlier drawings by Leonardo da Vinci, *c.* 1500, may be consulted in the *Codice Atlantico*, ff. 190 Ra, 263 R., 383 v.

A good series of illustrations of hollow geometrical solids may be seen in Peter Ryff, *Quaestiones Geometricae*, 1600, of which Sir Christopher Wren's own copy is preserved in the Bodleian Library.

30. Set of Geometric Solids. **c. 1690–1700.**

Picture Gallery, Bodleian Library.

The solids are grouped round the column, representing the five orders of Architecture.

The column is surmounted by a skeleton dodecahedron of stone, containing on an axis a brass dodecahedron with each pentagon filled with five triangles. Round the base are two tetrahedra and one broken octahedron of stone; and in bronze, two pyramids, a 2½-inch cube, a tetrahedron, and a dodecahedron; and there are vacant spaces for two other solids that have been lost.

31. A set of '**Sollid Bodys**'. Boxwood. **c. 1710.**

Orrery Collection at Christ Church, 43.

The set includes—3 tetrahedrons, 10 cubes of various sizes, 3 bisected cubes, 5 quarters and 1 eighth of a cube, 2 octahedrons, 2 dodecahedrons, 2 icosahedrons, 2 conic sections, and 1 dissected scalene prism.

32. **Geometric Solid** in boxwood. **? 1780.**

University Observatory.

Apparently of the period of Hornsby.

Two Cubes in brass. **c. 1823.**

By Rev. Lewis Evans, F.R.S., and his man Barton (d. 1827).
L. Evans collection.

One of the cubes has been skilfully perforated with a opening that is just large enough to admit of the passage of the other cube through it.

Spheres

The Sphere was an essential adjunct in education in Europe from the days of Gerbert onward.

'When Prince Henry was receiving instruction in mathematics from Edmund Wright, the latter for the more easy information of the Prince contrived a sphere of wood, about three quarters of a yard in diameter, which lay neglected and out of order in the Tower, at London, and Sir Jonas Moore begd it of his present majestie, who showed it to me.'—Aubrey's *Lives*.

33. **Two 4-inch Demonstration Spheres,** bisected on the ecliptic. **c. 1650.**

Savile Room, Bodleian Library.

These two small spheres of beechwood are all that remains of the elaborate instrumental outfit of the Savilian Professors which was kept in the *Cista Mathematica*. They doubtless represent No. 13 in the list of apparatus printed in the *Catalogus Librorum Manuscriptorum*, 1697, p. 302.

13. Globus ligneus in cotyla lignea motitans quadranti adserendus.

34. Three **Demonstration Spheres.** Boxwood. **c. 1700.**

Diameter $3\frac{1}{4}$ inches. Orrery Coll. 5.

Marked in ink to illustrate propositions on spherical triangles. Two of the spheres are supported in turned wooden pedestal cups.

Calculating Apparatus

In any complete catalogue of early Calculating Apparatus the ten Fingers, and even the Toes, should play a prominent part, even though we cannot show any that were contemporaneous with the mathematicians to whom they belonged. The Venerable Bede performed many calculations on his Fingers. In more recent times their place has been taken by mechanical contrivances of the kind enumerated below, and by Tables. We have not ourselves pursued this line of investigation in Oxford, but for those who may feel inclined to do so, the Bodleian MSS. contain many early examples. A compact *Multiplication Table* to 20 x 20 and a *Table of Cubes of Numbers* 1 to 10 may be consulted in the Book of J. Chaunteler, S. C. 2142.

35. Swampan, or Chinese calculating table. **17th cent.**

No. 63. Ashmolean Museum.

No name of a donor is recorded, so it may quite conceivably have formed part of the original Tradescant collection, or have been added to it by Ashmole, who owned some apparatus, for he 'bought of Mr. Milbourn all his books and Mathematical Instruments'. *Diary*, 13 Aug. 1650.

36. Swampan. **? 17th cent.**

No. 64. Ashmolean Museum.

Pres. by W. Lloyd.

These tablets are used for casting accounts. The two upper balls each stand for 5, and the lower balls for units.

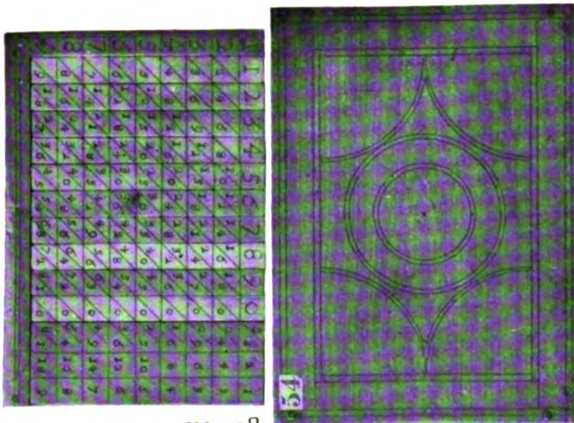
37. Abacus.

Size about 14 inches × 4½ inches.
? Rawlinson Bequest. Charter Case, Drawer 38.
Bodleian Library.

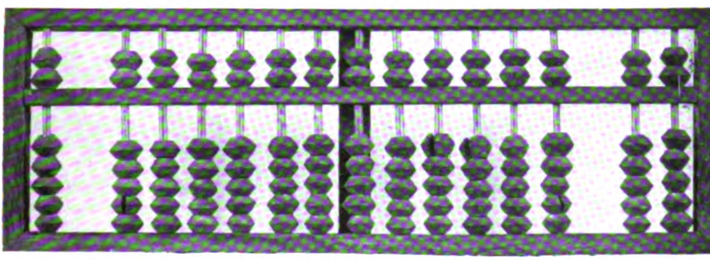
2 + 13 + 2 = 17 rows of beads, 2 + 5 in each row.[1]

The earliest reference to the use of the word Abacus to denote this instrument occurs in 1686 in *Misc. Cur.* iii. 216. In its older meaning an abacus was a board

[1] Roman abaci had one row of beads on top.



NO. 38



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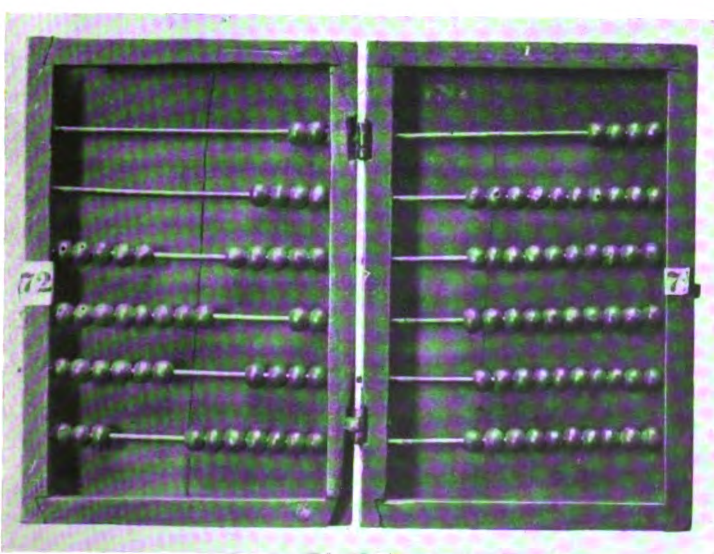
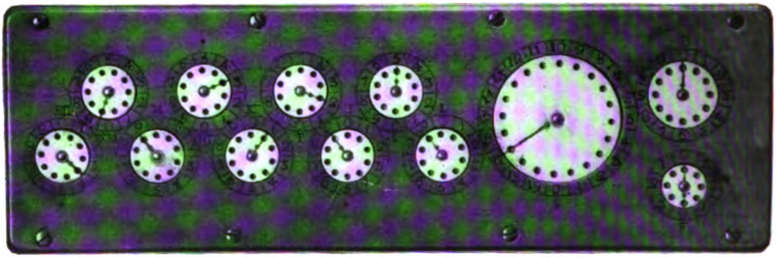


NO. 35

CALCULATING APPARATUS



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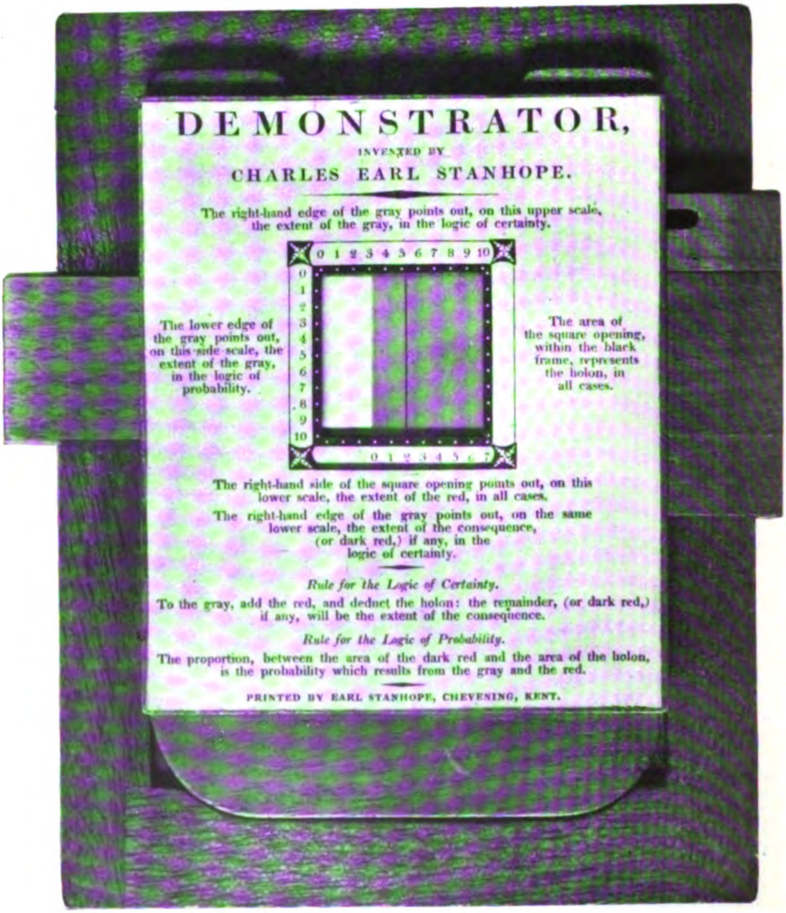


NO. 40

STANHOPE'S INVENTIONS

strewn with sand for the delineation of geometrical diagrams. (*N.E.D.*)

38. Napier's Bones. c. 1730.

In boxwood case, $3\frac{1}{2}$ inches × $2\frac{5}{8}$ inches.

Ashmolean Museum.

For multiplication and division on the system invented by John Napier of Merchiston (1550–1617).[1]

Morland's Adding Machine. 1666.

L. Evans collection.

Inscr.: *Samuel Morland Inventor 1666.*[2]

The mechanism is contained between two silver plates, measuring $4\frac{1}{2}$ in. × $2\frac{1}{2}$ in. pierced with eight apertures, inscribed *Ten Thousands*, *Thousands*, *Hundreds*, *Tens*, *Unites*, *Shillings*, *Pence*, *Farthings*. The dial-plates beneath each aperture could be revolved by an appropriate tommy, but there is no intermediate gearing between the lower and the higher values.

Hooke's Engine for Multiplying and Dividing.

c. 1670.

No example in Oxford.

Dr. Hooke of Christ Church was the inventor, about 1670, of an 'engine for multiplying and dividing' (MS. Birch 4422, f. 67); and the ingenious Marquis of Worcester (1601–67) refers to a similar instrument in his Century of Inventions.

Doubtless one of these Arithmetical Machines suggested the following invention of Lord Mahon.

39. Stanhope's Arithmetical Machine. 1780.

Ashmolean Museum.

Inscr.: *Visct Mahon Inv. 1780 Jas. Bullock fecit.*

The operations are conducted by means of dial-plates

[1] Uffenbach notes under date 27 June 1710 that he bought 'a globe, bacilli Neperiani, and a small but powerful magnet' in Westminster Hall. Circles, or arcs of circles, often formed part of the decoration of the boxes of these sets of bones. A dated set, inscribed '*Edm*[d] *blow fecit for Mr. Iulius Deedes* 1715', is in the L. Evans collection.

[2] Sir Samuel Morland's (Master of Mechanics to Charles II after the restoration) Arithmetical machine was mentioned in a letter of May 1666 (MS. Birch 4279) and published in 1673.

and small indices, movable with a steel pin. The mechanism was doubtless based on an earlier model. One of the first of these to be constructed in England was the Arithmetical Machine of Samuel Morland[1] (1662), by means of which the four fundamental rules of arithmetic are very readily worked, and, to use the author's own words, 'without charging the memory, disturbing the mind, or exposing the operations to any uncertainty.'

The brass base containing the mechanism is covered by a boxwood board in which are twelve ivory dial-plates marked

HM XM M HT XT T H X L S D F

The L, S, D, F obviously refer to pounds, shillings, pence, and farthings, and the HM, XM, and M to hundreds of thousands, tens of thousands, and thousands, but the exact use of the intermediate dial-plates is not very obvious, unless they be for hundreds of tens, tens of tens, and tens.

According to the Rev. R. Harley, F.R.S., four of these machines are in existence. One is in the hands of the present Earl, two others, of like construction, have come into the possession of General Babbage, and the fourth, a much smaller and less effective instrument, is in Mr. Harley's possession. *Mind*, iv, p. 195.

Charles, 3rd Earl Stanhope, 1753–1816, F.R.S., 1807, was considered by Lalande to be the best English mathematician of his day. His schemes for safeguarding buildings against fire were printed in the *Philosophical Transactions* for 1778; his experiments for propelling vessels, 1790–5, by the steam-engine were approved by the Lords of the Admiralty; his microscope, the Stanhope lens, is well known. Of special local interest is his process of stereotyping, which was acquired by the Delegates of the Clarendon Press at Oxford in 1805 on the condition that they paid £4,000 to the foreman and manager of his press. They also acquired his iron hand-press, called the Stanhope press, and his system of logotypes and logotype cases (*D.N.B.*). One of his portraits was reproduced by the Oxford Historical Society, *Collectanea*, vol. 3.

[1] See note 2 on p. 41.

40. Logic Demonstrator. 1777.

Ashmolean Museum.

Invented by Charles, 3rd Earl Stanhope.
Printed by Earl Stanhope, Chevening, Kent.

'The Demonstrator is a simple contrivance for the mechanical working of this rule. It consists of a brass plate four and a half inches long and four inches wide, affixed to a block of mahogany three quarters of an inch thick. In the centre there is a "square opening" or depression, about an inch and a half in area, and half and inch deep: this is called by Stanhope the *holon*. Across the *holon* two slides can be pushed; one, which is set in a slender mahogany frame, is of red transparent glass, and cannot be wholly withdrawn from the instrument; it works through an aperture on the right. The other is of wood, and seems to have been originally coloured gray, but to have become in the course of time bleached; this is spoken of by Stanhope as "the gray slider". In working the "Rule for the Logic of Certainty" this slide is passed through an aperture to the left; but in working another rule given by Stanhope, the "Rule for the Logic of Probability", it is drawn out and inserted in an aperture at the top, when of course it works at right angles to the red slide. In each case, when the slides are pushed in, the red covers the gray (or white). On the lower edge of the red slide, and on the upper edge of the square opening, the numerals

0, 1, 2, 3, 4, 5, 6, 7, 8, 9, 10.

are printed, with a white dot on a black ground opposite to each numeral. The same scale, running from top to bottom, is printed on the left side of the square opening. These scales serve to indicate the extent to which the slides are pushed in.'

On the face of the Demonstrator various rules and explanations are given, as in the accompanying figure.

'To Stanhope belongs the honour, and it is a very high honour, of being the first to attempt the solution of logical problems by a mechanical method.'[1] R. Harley, *Mind*, iv, p. 208.

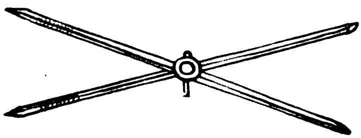
[1] Earl Stanhope devised and caused to be executed several instruments of various sizes and constructions for the same purpose.

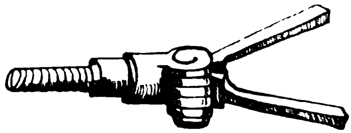
Drawing Instruments

The principle of the ordinary pair of compasses must have been known to every race of men in the dawn of their civilization. The Greeks distinguished the compasses (διαβήτης) from the circle-drawer (τόρνος). The Naples Museum can show Roman compasses from Pompeii or Herculaneum both with straight legs and with bent points. The legs were pivoted like the blades of scissors.

In the year 1100 compasses of iron were composed of two parts, a larger and a smaller, with straight or curved legs (Theophilus iii. c. 16).

The Italian instruments in use *c.* 1500 were figured by Leonardo da Vinci (*Cod. atl.* f. 375 Ra), including one





Proportional Compasses. Compass Joint.

After Leonardo da Vinci.

'*Cod. atl.*' 248 *Ra.* '*Cod. atl.*' 375 *Ra.*

with a joint formed of three leaves on one side and two on the other, and a very firm support. A more elaborate example is figured on f. 259 R and 259 v.

And at a later date the care bestowed by Italian craftsmen upon certain details in the construction of their instruments is noteworthy, as for instance in the case of the manner in which steel points were firmly inserted into the brass limbs of compasses. In the best work the tenon by which these steel points were fixed was expanded to form a knob which absolutely prevented withdrawal. My friend Mr. L. Evans drew my attention to this refinement in the case of a pair of dividers marked 'Jacobus Lusuerq Faciebat Roma 1687', and

The most convenient is the one described in the text, of which there are duplicates. One of these has been presented to Mr. R. Harley by the sixth Earl; the other is retained in the family. It is probable that this was the last form of the instrument which Stanhope devised. The others are less simple in construction and less effective in operation.

the same detail may be observed in a pair presented by him to the Masonic Lodge of Antiquity, No. 2 Grand Lodge of England.

Other illustrations of contemporary compasses may be consulted in Peter Ryff, *Quaestiones Geometricae*, 1600, p. 13;

After Clavius. *After Ryff.*

Furttenbach, *Mechanischen Reissladen*, Augsburg, 1644, gives a number of copper plates of instruments; Clavius, *Gnomics*, 1681, fig. on p. 35.

Compasses with one limb fitted with an arc that holds the other leg in position were common in the sixteenth century. They were much used by smiths. Cf. Landauer Portrait book, 1608, pl. 62; ditto, 1625, pl. 95; ditto, 1635, pl. 95 v.

In 1633 Joachim Deuerlein contrived Compasses for secret writing, which were to be seen, together with many other specimens, in the Mathematical Physical Gallery at Dresden.

In England at about the same time the best instruments were obtainable, as it seems, only in London: for Oughtred. who lived in the country and affected to despise persons who taught mathematics with the help of instruments, was on more than one occasion hindered in his work for the want of them. In 1633 he wrote 'and because I seldomely came to London, where I might have the helpe of large Compasses, and other Instruments, for drawing the arches of very big circles; I was forced to betake my selfe to such shift, as Art would afford me, and invented many Theoremes . . .'

Drawing pens composed of two adjustable laminae between which ink is held were the invention of the Romans. The adjustment for thickness of line was effected by a sliding bar. In the sixteenth century the grooved pen of earlier days was still frequently used for ink.

Sets of Drawing Instruments

The excellence of the workmanship that was sometimes bestowed on early sets of drawing instruments is most remarkable and bears evidence to the value set upon them. A superb instance of such a set *de luxe*[1] is believed to have been made by a Milanese master craftsman about 1540. With the instruments is an iron casket, measuring $8\frac{1}{8} \times 2\frac{3}{4} \times 1\frac{3}{4}$ inches, most carefully and minutely damascened with arabesques in silver and gold, truly a marvel of patient elaboration.

The instruments are twelve in number and are damascened from end to end. They comprise

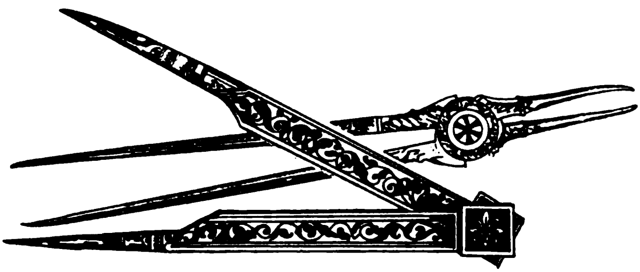
1., 2. } Two pairs of compasses with bow tops $6\frac{1}{2}$ in. long.
3. Three pairs of compasses, *a.* with plain points.
4. *b.* with one point leaf-shaped and slightly curved for ink.
5. *c.* with a split tube for crayons.
6. A crayon-holder with urn-shaped top at one end, and a tubular holder at the other, $6\frac{5}{8}$ in. long.
7. Another instrument with a flattened fork at the end, perhaps for holding a small sponge.
8. Three proportional compasses, *a.* 2 to 1.
9. *b.* 3 to 1.
10. *c.* 4 to 1.
11. Ruler and compasses combined. The rectangular stem is divided into inches of about 27 mm., a measure which does not seem to agree with any of the old Italian standards, but which agrees very closely with the old French foot, as shown by an instrument, dated 1617, by Volkmaer, and which was in use down to the introduction of the metric system. Each inch is subdivided into various portions, as 10ths, 12ths, 24ths.
12. Joint rule of 6 inches French measure ($=1\frac{1}{16}$ in. English). The Divisions are variously ornamented.

The discrepancy between the nationality of the work and of that of the unit of measure lends colour to the suggestion that this beautiful case of instruments may have been a gift from a North Italian prince to a French King.

[1] No. 6593 in the Catalogue of the Special Exhibition of Works of Art at S. Kensington in June 1862, and now in the possession of Mr. L. Evans, who has permitted us to print a description of his treasure.

In the sixteenth and seventeenth centuries the smaller instruments were commonly sold in cases, in sets which usually included Compasses with fixed and movable points, a drawing pen point, a pencil point, and sometimes a dotting wheel, a ruler, a drawing pen, a porte-crayon, and a protractor.

In the eighteenth century the smaller cases of instruments were made in upright form, and rather rectangular in cross-section like the French Cases figured by Stone on Plate VI, or oval like the English Cases shown on the same plate. We do not know which was the older fashion; the English cases of the sixteenth century were rectangular, as was that of the beautiful sets of instruments made by Barth. Newsum.[1] The idea of the case



PROPORTIONAL COMPASSES AND DIVIDERS, BY NEWSUM.

may have been derived from the knife and fork cases which were introduced about the time of James I.

Early in the eighteenth century at least three London makers, Glynne, Rowley, and Heath, were renowned for the excellence of their workmanship. The work of GLYNNE is still represented by an upright box of silver drawing instruments, which are like those of Rowley in design, but have washers of gold to the compasses. Inside the lid is an engraved design of Hercules carrying the Globe, perhaps the street-sign of the maker's place of business, and the inscription 'Glynne fecit' but no date. The set of instruments include: 1. A 6-inch Sector. 2. Cross-bar Parallel Rulers and Protractor, with a foliated border on under-side. 3. Diagonal Plotting Scale. 4. Compasses with *a*. Pen, *b*. Crayon-holder,

[1] See p. 87.

c. Dotting wheel. 5. Dividers. 6. Tommy and turn-screw. They are contained in a silver-mounted leather case, with foliated borders, 6¾ in. high.

A second example of his work is seen in a silver-mounted case of miniature instruments 3¾ inches in height. The set includes: 1. A 3-inch Sector and Protractor, marked 'R. Glynne Fecit', with scales marked 'H, T.C, T, Cho, S, L.S., S, S.L.' A folding arc serves as a protractor. 2. 3¼-inch Parallel Rulers, with cross-bar, diagonal scale, scales of *Sin*, *Cho*, *Tan*, *Hou*[*rs*]. 3. 3-inch Compasses, with pen, pencil, and dotting wheel, all hinged. 4. Ruling Pen with Pricker. 5. Pencil.

The side of the case bears the crest of an owner, a Wyvern sitting on a crown. (L. E.)

Thomas Heath was the maker of an oval, upright case 5½ inches high, containing: 1. 4¼-inch Sector in ivory with a hinge of silver, opening to form a Square. 2. Parallel Rulers with cross-bar, with Protractor above, and Plotting Scales divided to $\frac{1}{10}$ths and $\frac{1}{100}$ths of an inch beneath: borders foliated. 3. 4¼-inch Compasses with points, pen, and pencil, all on swivels. 4. Dividers. 5. Ruling Pen. 6. Pencil-holder. 7. Tommy. (L. E.)

Larger sets of instruments like Rowley's were packed in flat rectangular boxes. And it was probably of such sets that Stone wrote in 1758 that 'the Making of good Mathematical Instruments is almost peculiar to the English'.

41. Miniature Case of Instruments. **c. 1640.**

Formerly the property of John Milton.

Deposited by the owner in the Bodleian Library.

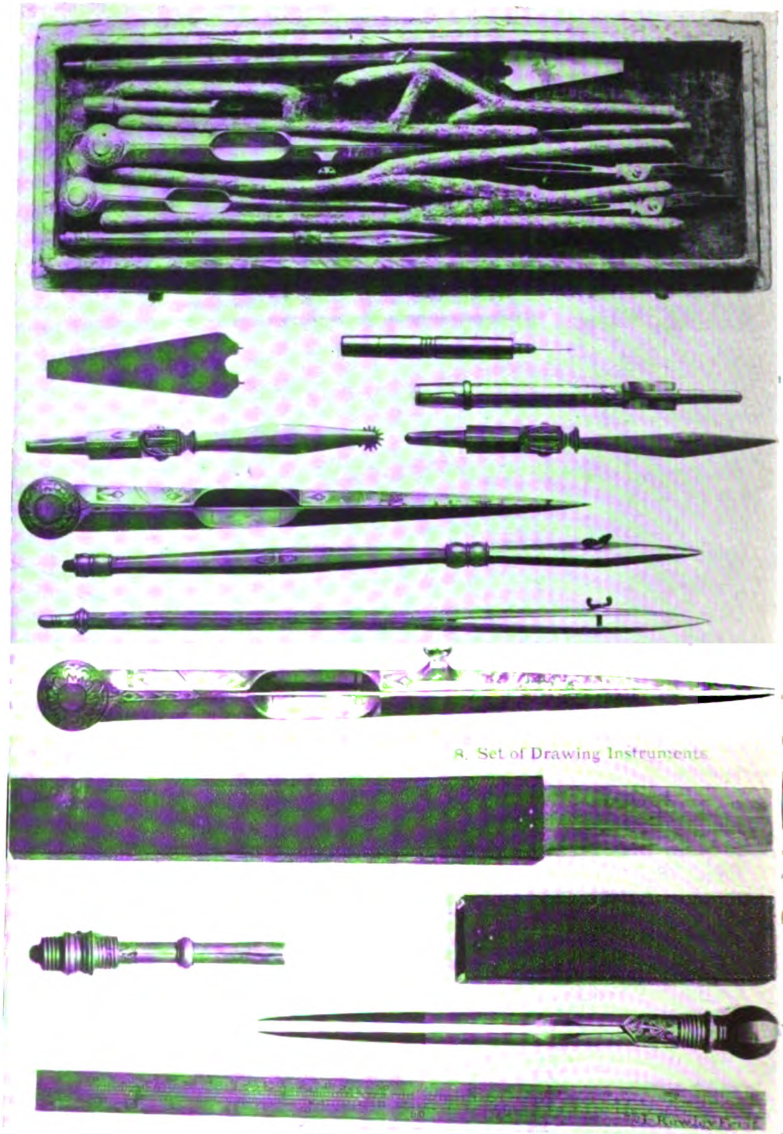
The only instruments left are a small pair of dividers 2½ inches in length, and a book of 3 ivory writing tablets. The Dividers, which have been broken, are so designed that one leg closes like the blade of a pocket-knife into the other leg.

The case is rectangular of tortoise-shell.

42. Set of Drawing Instruments. **c. 1690.**

In flat case. By Rowley. Orrery Coll. (34).

Silver with chased decorations. The set includes a pair of 6½-inch compasses, with pen, pencil-holder, and



NOS. 42 AND 45. ROWLEY'S INSTRUMENTS

dotting wheel; 5-inch dividers; ruling pen; turnscrew; and a long ruling pen that may have belonged to a different set.

Large **Brass Compasses.** **Before 1697.**

Savile Collection, now missing.

'Circini magni aere armati.'

Cat. libr. manuscr. 1697, p. 302.

43. 13-inch Compasses. 17—.

Wood and iron (broken). Oriel College.

Steel Callipers for very accurate measurement. 1777.

No. 69. Royal Society.

By Paull, of Geneva.

Proportional Compasses

In the fixed Proportional Compasses known to the Romans the proportion of the long legs to the short legs was fixed so as to effect an enlargement or reduction in constant ratio, e.g. $1:1\frac{1}{2}$ or $1:3$. In an instrument found at Pompeii the limbs are pivoted on a slotted pin and held together by a wedge.

The fine early Italian set of three described above, are for the ratios of $1:2$, $1:3$, and $1:4$. An early English example by Newsum is figured on p. 47.

Adjustable Proportional Compasses were known to Leonardo da Vinci, c. 1500 (cf. *Cod. atl.* f. 248 Ra; MS. *Forster* 141, f. 4, S. Kensington), and instruments of similar construction were described in Besson, p. 2. Also cf. Speckle, *Architectura*, Strasburg, 1589.

Printed descriptions of Adjustable Proportional Compasses appeared in several books early in the seventeenth century, as in Hulsius, *Tractatus tertius Instrumentorum Mechanicorum*, 1605, which was illustrated with a figure of the instrument on the title-page. The author is careful to point out the 'Centrum cum suo nodo mobile' and attributes the invention of the 'Circini Proportionales' to Just Burgi.

Georg Galgemair in his *Porportional Schregmäss und Circkel*, 1615, and *Ein newer Proportional-Cirkel*, 1626,

discussed the special utility of the instrument to Surveyors.

44. Adjustable Proportional Compasses. c. 1700.

Silver with steel points. $7\frac{1}{2}$ inches in length.
Orrery Coll. (20).

Inscr.: John Rowley Londini Fecit.

In original wooden case covered with shagreen. The engraved scales are lettered 'Lineae rectae, Divisiones Circuli, Divisiones Planorum, Divisiones solidorum', and on one side is an explanatory diagram with the equation 'Vza = b'.

45. Four-sided Scale with **Compasses** in one end and a **Pencil-holder** in the other. (See p. 54.) c. 1700.

Silver, 6 inches in length. In original case.
Orrery Coll. (21).

Inscr.: I. Rowley Fecit.

The Compasses have a thick head, reminiscent of the Italian model.

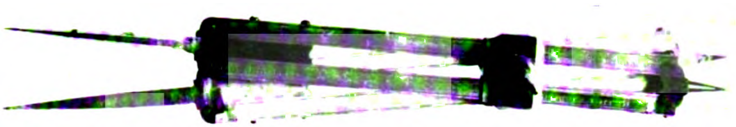
Parallel Rulers

In spite of the fact that Charles Dodgson of Christ Church (Lewis Carroll) some fifty years since printed a plea for a Mathematical Laboratory in Oxford, with a strip of the Parks railed off for the investigation of the properties of parallel lines, which strip of land, said the writer, should reach 'ever so far', Oxford collections are singularly deficient in early examples of Parallel Rulers. The better instruments made by Rowley's contemporaries were furnished with cross-bars in the place of the single bars sloping one way, and many were engraved with scales as well. An interesting type of Rolling Parallel Ruler invented by A. G. Eckhardt was made by P. and J. Dollond of St. Paul's Churchyard. Both this and a more modern instrument of star-shaped section are in Mr. L. Evans's collection.

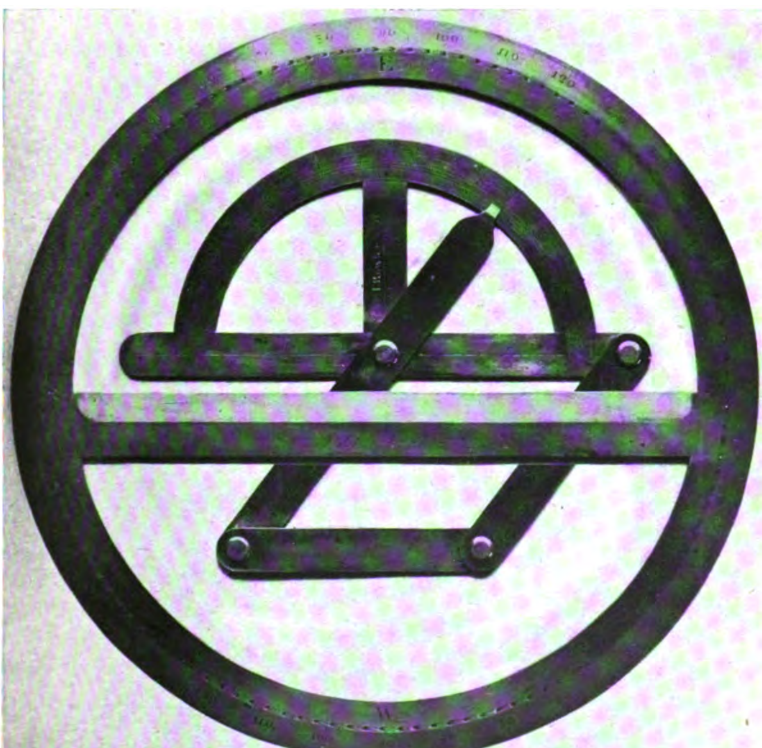
46. Parallel Rulers. c. 1700.

Ebony, 7 inches long. Orrery Coll. (46 a).

Cf. Stone's *Bion*, Pl. X, Fig. R.



NO. 44. PROPORTIONAL COMPASSES



NOS. 48 AND 49 PROTRACTORS

Protractors

Disk Protractor. c. 1680.

Silver; diameter 5 inches. L. Evans collection.

Inscr.: J. Marke fe.

Semicircular Protractor and **Scale.**

Original Drawing by Edmund Gunter. See p. 120.

47. **Rectangular Protractor.** c. 1700.

Ivory, 6 inches. Orrery coll. (46 b).

Inscr.: I. Rowley Fecit.

With a scale of $\frac{1}{24}$th of an inch along one edge.

48. **Recipient Angle** or **Semicircular Protractor.** c. 1700.

Radius 4 inches. Orrery coll. (49 ?).

Inscr.: I Rowley fecit.

Semicircle graduated 0°–180° in both directions. Fitted with adjustable rulers, marked Ext. and Int^{r}., as in Stone's *Bion*, Pl. XI, Fig. D. This type of instrument was of great use for plotting fortifications.

49. **Circular Protractor.** c. 1735–7.

Diameter $12\frac{3}{4}$ inches. Christ Church.

Inscr.: *J. Sisson, LONDON.*

Divided to $\frac{1}{2}$ degrees. A very beautifully graduated instrument.

Semicircular Protractor. c. 1735.

Brass; diameter 5 inches. L. Evans collection.

Engraved with the maker's mark
S
I ∗ S

and *I SISSON FECIT.* A beautifully worked instrument.

Protractor, 10-inch. **Before 1834.**

No. 61. Royal Society.

Inscr.: Ramsden.

Reading to minutes with a vernier.

Circular Protractor, 6-inch. **Before 1834.**
No. 82. Royal Society.

Inscr.: Troughton and Simms.

50. Large **Rectangular Protractor.** **Early 19th cent.**
Radcliffe Observatory.

With rotating bar and perpendicular scale.

Elliptical Trammel

The principle involved in the elliptical trammel was known to the Greek geometers. Proclus (A. D. 410–485), of the Platonic school at Athens, in his commentary to Euclid, gave a method for the mechanical construction of an ellipse, which was based on the use of the instrument described by Nicomedes (born about 270 B. C.).

The so-called 'gardener's construction' of the ellipse by means of a pencil and a string tied to two fixed points was discovered by Alhasan, youngest son of Musa Ibn Schaker, a prominent member of the court of Caliph Al-Mamum, 813–833.

51. **Elliptical Trammel,** 19 in. × 8 in. **Before 1759.**
Christ Church.

Inscr.: *Josph Jackson, London.*

A fine instrument with micrometer screw adjustment and ruling pen. In T-shaped box.

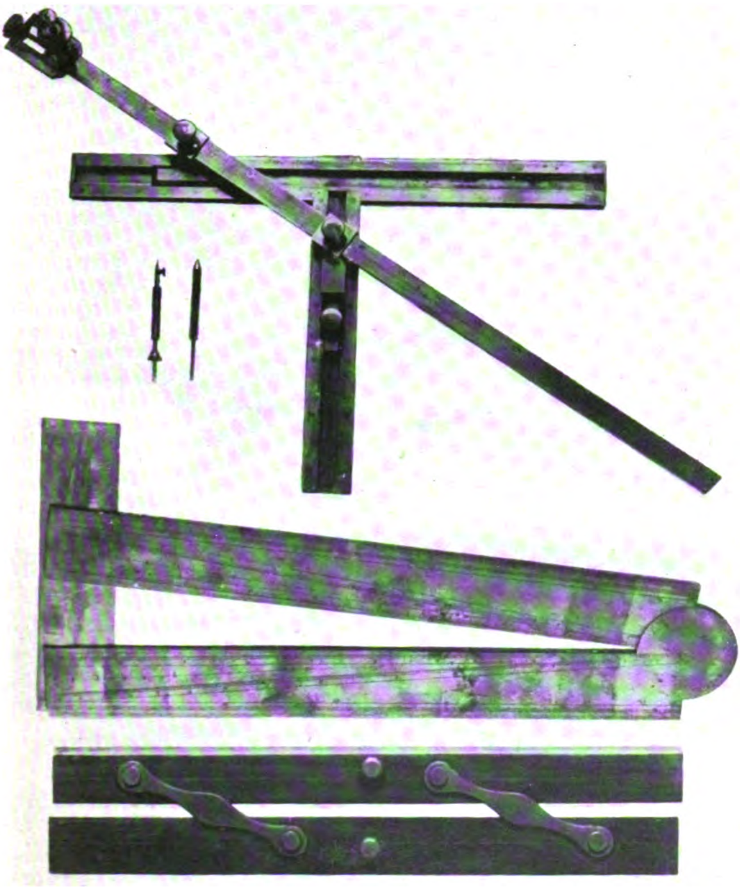
A letter from J. Bird to Dr. Fanshaw apparently refers to this instrument.

To the Revd. Dr. Fanshawe
Oxford.

London 6th Jany 1759.

Sir

I return'd your Instrument last Thursday by Parson's waggon. I might have sent it sooner, if I had not waited for an opportunity of consulting Dr. Bradley about it, the result of which, was to put labels to the screws that are to be fasten'd, and eased, for the purpose you require. I had not your letter with me when I was with the Dr. therefore did not think of mentioning what you propose i.e. making the distance between the Pole and the Asymptote assignable, but if you consider the use of ye divisions already upon



NO. 51. ELLIPTICAL TRAMMEL
NO. 56. SECTOR
NO. 46. PARALLEL RULERS

it, I apprehend you'll be under no difficulty in that respect. As the Ink point (in this case) alters its position with regard to the line it draws, it was thought necessary to make two other points; one to carry a pencil, the other to draw what is called a dry line: the nut upon one of them serves for both, and in the socket where the points go, is a small worm spring, which will answer for all the points.

I am Sir your most obedient serv[t]. J. BIRD.

52. Parabolic Curve. Brass. **c. 1760.**

Christ Church.

Inscr.: *Nairne & Blunt*, London.

Perhaps of the period of Dr. Fanshaw.

PARABOLIC COMPASSES

c. 1500 Leonardo depicted one that was used for the construction of parabolic mirrors. (Feldhaus, *Leonardo*, Jena, 1913, p. 114.)

SCALES

Plotting Scales are frequently found engraved upon some part, usually the sight rule of Surveying instruments. A good example is contained in the Evans collection. The instrument is a German Surveying Compass and Sundial of gilt brass mounted on a wood base. It is marked 'C.T.M.F 1608'. The sight rule is engraved with a diagonal scale with subdivisions to read to $\frac{1}{1000}$ of the whole.

Alidades for use on Plane Tables were also frequently engraved with Plotting and Diagonal Scales, as in the case of two of 2-feet marked 'B. Scott fecit' in the same collection. And the Christ Church Plane Table by Worgan is provided with an alidade of the same kind.

Several Scales combined with Parallel Rulers have already been mentioned. In combination with rectangular Protractors, Scales are common enough, e.g. '*Edm. Culpeper Londini Fecit*', a 6¼ in. silver Protractor with Plotting Scales, Diagonal Scale, and Scales for R.C.S. T.ST. Eq.P. '*W[m] Parsons Fecit*' in brass, a similar but less elaborate instrument (L.E.).

45. 6-inch Plotting Scale, with Compasses. **c. 1700.**

Silver. (See p. 50.)

Inscr.: I. Rowley fecit.

The scales are lettered, 'Num. Sin. Tan. E.P.' (=Equal Parts) 'Cho.' The construction is similar to that of the octagonal scale or rule figured in Stone's *Bion*, Pl. X, Fig. A.

53. 12-inch Plotting Scale. Boxwood. **c. 1700.**

Orrery coll.

On front, scale of inches divided in $\frac{1}{10}$ths, and the ordinary plotting scale with diagonal lines (Stone's *Bion*, Pl. IV, Fig. 2). On the back, Plain scales (l. c., Fig. 6). Scales marked Le[agues] Rvm[bs] Cho[rds] Sin[es] Tan[gents] H[alf] T[angents] Lon[gitudes].

54. 5-inch Plotting Scale. **c. 1700.**

Brass, in original case. ? Orrery coll. (35 ?).

Inscr.: S. HORSEMAN.

Scales of $\frac{1}{10}$, $\frac{1}{20}$, $\frac{1}{30}$, $\frac{1}{100}$, $\frac{1}{200}$, $\frac{1}{300}$, inch.

55. 2-foot Composite Scale. Boxwood. **18th cent.**

Formerly the property of President Bellamy, now in the possession of Mr. F. W. Hall of St. John's College. The scales include

1. 9-inch **Plotting Scale** with diagonal lines.

2. **Plain Scale.**
   Rum[bs]
   Cho[rds]
   Sin[es]
   Tan[gents]
   S T[angents]

3. **Gunter's Scale.**[1]
   S R = Sines of the Rhumbs
   T R = Tangents ,,
   Num = Gunter's Line of Numbers
   Sin = Line of Sines
   V S = Versed Sines
   Tan = Tangents
   Mer = Meridian Line
   EP = Equal Parts.

4. **Plotting Scale.**
   Lea[ ]?
   Rum[bs]
   M L = Meridian Line, used to project a Mercator's Chart.
   Cho[rds]

[1] Cf. Stone's *Bion*, Pl. V, Fig. 6.

SECTORS

The Sector is an instrument of two equal rules or legs of silver, brass, ivory, or wood joined by a rivet, by which may be found the proportion between quantities of the same kind; as between one line and another, between one area and another, or between one volume and another.

A forerunner of the English Sector was the Geometric and Military Compass invented by Galileo about 1596–7.[1] It consists of two straight rulers connected by a joint so that they can be set to any required angle. On one face are four pairs of lines:

Arithmetical Lines, which serve for the division of lines, the solution of the Rule of Three, the equalization of money, the calculation of interest.

Geometrical Lines, for reducing proportionally superficial figures, extracting the square root, regulating the front and flank formation of armies, and finding the mean proportional.

Stereometrical Lines, for the proportional reduction of similar solids, the extraction of the cube root, the finding of two mean proportionals, and for the transformation of a parallelopiped into a cube.

Metallic Lines, for finding the proportional weights of metals, and other substances, for transforming a given body into one of another material, and of a given weight.

On the other side of the instrument are:

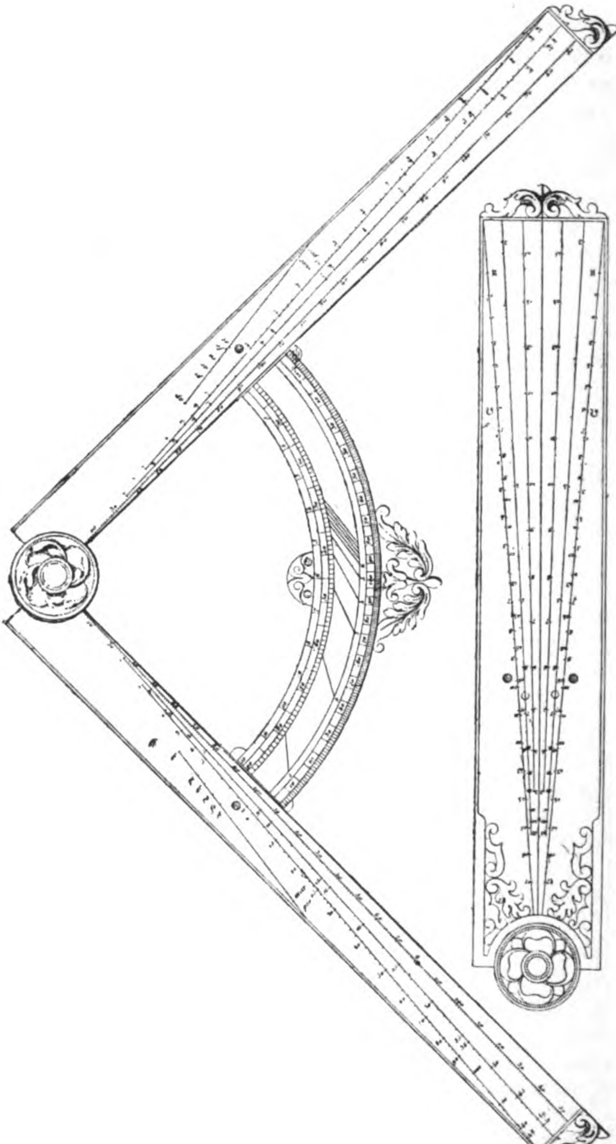
Polygraphic Lines, for describing regular polygons, and dividing the circumference into equal parts.

Tetragonical Lines, for squaring the circle or any other regular figure, for reducing several regular figures to one figure, and for transforming an irregular rectilineal figure into a regular one.

Joined Lines, used in the squaring of the various portions of the circle and of other figures contained by parts of the circumference, or by straight and curved lines together.

There is joined to the Geometric Compass a quadrant, which, besides the usual divisions of the astronomical

[1] This useful instrument was described in Galileo's first published work, *Operazioni del Compasso Geometrico e Militare*, Padua, 10 July 1606, and is figured facing p. 42 of J. J. Fahie's *Galileo*, 1903.



THE GEOMETRIC AND MILITARY COMPASS OF GALILEO.

compass, has engraved on it a squadron of bombardiers, and, in addition, transversal lines used for taking the inclination of a scarp of a wall.

Large numbers of these instruments, in copper and silver, as well as of drawing instruments, were manufactured in a workshop in Galileo's own house. On 5 July 1599, 'Messer Marcantonio Mazzoleni, mechanician, comes to reside in my house to work for me, and at my cost, on mathematical instruments, I undertaking to bear the expenses of him, his wife, and child, and to pay him in addition the sum of six ducats per annum'.[1]

The utility of the instrument was speedily recognized, and amongst others by 'one of those parasites who live at the expense of the talent and the renown of others'. Within a few months of the publication of Galileo's treatise on his instrument a certain Baldassare Capra claimed the invention as his own and accused Galileo of piracy.

Fortunately Galileo was able to produce such evidence of the priority of his invention that the authorities of the University of Padua unanimously decreed Capra's book to be a scandalous plagiary and an insult to Galileo and the University.[2]

In England the invention of the Sector is attributed to Thomas Hood in 1598.[3] And by 1624 it had been considerably improved by Edmund Gunter, whose improved Sector was manufactured by Elias Allen. The three lines on most sectors marked N.S.T. are lines of log. numbers, log. sines, and log. tangents respectively. Gunter's scale facilitates the rough solution of many problems in areas, heights, cubic contents, &c. They are described in his *Book of the Sector* and in William Leybourn's *Line of Proportion*.

It is obvious that the longer the Line of Numbers, the better; and so various ways of prolonging it came to be adopted. Firstly by the inventor, *Edmund Gunter*,

[1] Galileo's *Diary*, quoted from Fahie.

[2] Galileo appears to have fastened the real blame upon a German graduate of Padua, Simon Mayer, who, later on, arrogated to himself the merit of some of Galileo's other discoveries. On this occasion Mayer hastily fled from Italy (Fahie, l. c., p. 46).

[3] Thomas Hood, *Making and Use of the Sector*, 1598.

upon rules of two feet and of three feet, wherefore it was called Gunter's Line; 'then that Line was doubled or laid so together, that you might work either right on, or cross from one to another, by Mr. *Windgate*; afterwards projected in a Circle, by Mr. *Oughtred*, and also to slide one by another, by the same author; and last of all projected into a kind of Spiral of 5, 10 or 20 turns, more or less by Mr. *Brown*, the uses being in all of them in a manner the same, only some with Compasses, as Mr. Gunter's and Mr. Windgate's; some with flat compasses, or an opening index as Mr. Oughtred's and Mr. Brown's; and some without either, as the Sliding Rules.'[1]

The following English makers of Sectors are represented in the Evans collection.

John Allen	9-inch	Sector	in	brass.
W. Collier	6	,,	,,	,,
Edm. Culpeper	12	,,	,,	,,
Wm. Deane	$4\frac{1}{2}$	,,	,,	,,
Dollond	6	,,	,,	silver.
R. Glynne	6	,,	,,	,,
T. Heath	$4\frac{1}{4}$	,,	,,	ivory.

And another fine $8\frac{3}{5}$-inch instrument marked '*Nicolaus Blondo Fecit Neapoli A*° 1694' with a cogwheel skilfully inserted in the hinge, shows that first-class instruments were made at Naples at the end of the seventeenth century.

56. 12-inch Sector. c. 1620–30.

Brass, in deal box. Christ Church.

Unmarked with the name of a maker, but in style the figures are very like those of Elias Allen. Cf. the long 4's and the 5's and 6's. It might be interesting to compare it with the 9-inch sector, marked 'John Allen fecit', in the Evans collection.

This fine sector includes the scale of metals, marked with planetary signs, in addition to the usual scales of sines, tangents, &c. It appears to be an improvement of Gunter's sector figured in Leybourn's 1673 edition of *The works of that Famous Mathematician*, &c.

[1] Stone's *Bion's Instr.*, p. 16.

57. 9-inch Sector. c. 1710.

Ivory, with silver hinge. Orrery coll.

Inscr.: I Rowley fecit.

The Scales are for 'Sin[es] Tan[gents] Cho[rds] Sec[ants] Lin[es] Num[bers] and Poll[ygons]'. It resembles the 'English Sector' figured in Stone, Pl. VI, but the scales are differently arranged. It is also like the sectors made by Sissons.

58. 6-inch Sector. c. 1720.

Ivory, with brass hinge. ? Orrery coll.

Apparently by Rowley, but unmarked.

The nearest approach to this sector that I have seen is the instrument made by Th. Heath, and described in S. Cunn's *New Treatise of the Construction and Use of the Sector*, revised by E. Stone, 1729.

59. 6½-inch French Sector. c. 1780.

In the possession of R. Gunther.

Inscr.: *Le Grand A Paris.*

A full description of this sector and its uses is given in Stone's *Bion*, pp. 46 et seq. It is engraved on one side with scales for *les parties Egalles*, *les plans*, *Poligones*, *Calibre des pièces*, and on the other side with scales for *les Cordes*, *les Solides*, *les Métaux*, and *poids des boulets*.

French Sectors.

Sectors inscribed by the following makers are represented in the Evans collection, but unfortunately the instruments are usually undated.

Butterfield à Paris. A large 13½-inch Sector mounted on ball and socket joint for the head of a tripod and furnished with an ornamented bracket, perhaps to carry a compass for surveying.

Cadot à Lion	4⅘-in. Sector, dated 1747.	
Clerget à Paris	3¼ „ „	in silver, opening to make a Square.
Gary à Paris	6½ „ „	.
Le Maire à Paris	6½ „ „	, opening to make a Square.

60. Military Scales or Counters. **? 1677.**

Orrery coll.

A set of nine rectangular brass plates in the original oak box, with spring catch. These were a great puzzle, but as four are marked 'Grenadiers', I believe that they may have been used for plotting the positions of Companies or Battalions—perhaps for estimating the areas that a given number of men will cover. The Earl of Orrery's uncle, Roger, wrote a *Treatise on the Art of War*, 1677. They may have belonged to him. The 'Ordering of Souldiers, in any kinde of rectangular forme of battaile', was set forth in chapter xi of W. O[ughtred's] *Circles of Proportion*, 1632, but we have not found any mention of such brass plates as these.

The long 'Counters' measure $4\frac{1}{2}$ in. × $\frac{7}{10}$ in. Four are marked for the *1st*, *2nd*, *3rd*, and *4th Division* respectively, with a square at one end marked *Angle*.

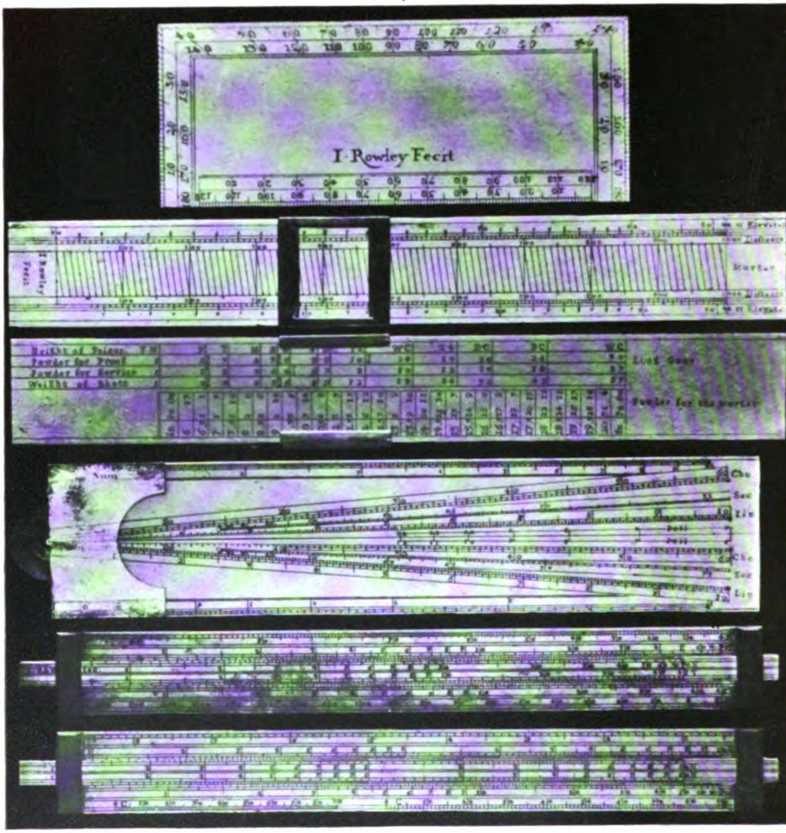
		1st Division.	
Angle	1	3	2
	1	1	1

A fifth is marked

Grs.	1	2	1	2	1	2	C	2	1	2	1	2	1	Grs.
1	1	1	3	3	5	5	3	6	6	4	4	2	2	2

Four counters of half the length are marked *Grenadiers* 1, 2, 3 and 4 respectively.

Grenadiers 4.



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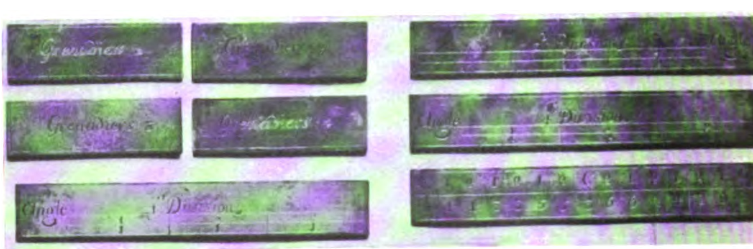
61
57
63
63

SCALES



NO. 60. MILITARY SCALES

61. 10-inch Artillerist's Gunnery Scale. **c. 1710.**

Ivory, with silver slider. Orrery coll.

Inscr.: I Rowley Fecit.

Scales of elevation and distance for mortars and quantity of powder needed, from 13 oz. for a 6-inch mortar, to 31 lb. 4 oz. for a 20-inch mortar. Also scales marked

$$\text{Long Guns.}\left\{\begin{array}{l}\text{Height of peices.}\\ \text{Powder for Proof.}\\ \text{Powder for Service.}\\ \text{Weight of Shott.}\end{array}\right.$$

The form of slider on this scale was in use at least as early as 1617. It occurs on a gilt brass joint rule (L. E.) made by '*Christof Tressler der Elter Mechanicus Anno* 1617', in which the legs marked AE and AF are provided with sliders G and H, moving over oblique lines, by which distances are measurable to $\frac{1}{100}$ inch.

Slide Rules

The saying that a prophet has no honour in his own country is well exemplified in the case of the Slide Rule and its inventors. For many years this useful instrument was greatly undervalued in England, the country in which it was invented, and even as late as 1850 it was very little known on the Continent. Yet, as De Morgan has aptly put it, for a few shillings most persons might put into their pockets some hundred times as much power of calculation as they have in their heads: and the use of the instrument is attainable without any knowledge of the properties of logarithms, on which its principle depends.

The following chronological summary[1] may help to elucidate the relationship of the few examples of old slide rules that are still extant in Oxford: among these is one of the very first circular slide rules made, and the oldest now extant.

[1] The principal facts relating to the history of the slide rule are contained in F. Cajori, *History of the Logarithmic Slide Rule*, 1909; J. W. Woolgar, *Mechanic's Magazine*, vol. xiv, pp. 308-11, 1831; and G. Stokes, *The Slide Rule*, 1914.

1620 The straight Logarithmic Scale was invented by *Gunter*. Calculations were made with it by the aid of compasses.

c. 1621 The straight Logarithmic Slide Rule is believed to have been invented by *William Oughtred* who used two rulers which he slid along each other. He is also said to have cast Gunter's Line into a ring, 'with another moveable circle upon it'.

1630 Oughtred demonstrated both his slide rules, linear and circular, to his pupil William Forster.

1630 Delamain's *Grammelogia* or Circular Slide Rule published.

1632 William Forster, teacher of mathematics in London, published a description of Oughtred's instruments under the title *The Circles of Proportion and the Horizontal Instrument*, London, 1632.

1635 Date engraved upon the Oxford Instrument made by Elias Allen.

1650 Milburne designed the first spiral logarithmic scale.

1654 Robert Bissacker made a Slide Rule for T.W. which is preserved in the South Kensington Museum.[1] This instrument antedates Seth Partridge's supposed invention of the slider by three years.

This very early example of the instrument is of boxwood, well made and bound together with brass at the two ends. It is of the square type, a little more than 2 ft. in length and bears Gunter's logarithmic lines.

Of these the *num.*, *sin.*, and *tan.* lines are arranged in pairs, identical and contiguous, one line in each pair being on the fixed part, and the other on the slide.

1657 The 'invention' embodied in Bissacker's Slide Rule was attributed to Partridge.

1675 Newton solved cubic equations by means of three parallel logarithmic scales, and made the first suggestion towards the use of a runner.

1722 Warner used square and cube scales.

1733 Scott's Circular Scale.

1748 Adam's Spiral Scale.

1755 T. Everard inverted the logarithmic scale and adapted the slide rule to gauging.

1755 Leadbetter's Rule with three Slides.

1775 Robertson constructed a 'runner', but though usually called the first of its kind it was anticipated by Delamain's invention in 1630.

[1] Baxandall, *An Early Slide Rule*, *Nature*, 5 March 1914: cf. *Napier Tercentenary Handbook*, 1914, pp. 163–5.

1787 Nicholson designed the logarithmic scale in sections, and displaced fixed scales relatively.
1815 Roget's log-log scale. (Made by J. Rooker.)
1840 J. W. Woolgar (of 47 Essex St., Strand) generalized the logarithmic scale and applied the slide rule to annuities.
1850 Mannheim designed the modern standard British slide rule, constructed the first cylindrical type, and popularized the runner.[1]

We possess in Oxford an important part of the earliest known Slide Rule, designed by the inventor of the instrument himself, and so far as we know, this instrument is absolutely unique.

William Oughtred is stated by Hutton, *Mathematical Dictionary*, to have applied logarithms to concentric circles as early as 1627. There is nothing improbable in this, for Oughtred had been consulted by Briggs concerning the perfecting of Lord Napier's plan, very shortly after the publication of the latter's *Mirifici logarithmorum canonis Descriptio* in 1614.[2]

Oughtred's merit as the real inventor of the Slide Rule was recognized by De Morgan.[3] He was a man who set but little value upon instrumental aids, unless in the hands of those who had previously learned sound principles. In the year 1630 he showed his slide rule to his pupil William Forster, who obtained permission to translate and publish his own description of the instrument, and rules for using it. This was done under the title *The Circles of Proportion and the Horizontal Instrument.* London, 1632; followed in 1633 by an *Addition, &c.*, with an appendix, having title *The Declaration of the Two Rulers for Calculation.* The following extract from W. Forster's dedication to Sir Kenelm Digby will explain the whole:

'Being in the time of the long vacation 1630, in the Country, at the house of the Reverend, and my most worthy friend and Teacher, Mr. William Oughtred (to whose instruction I owe both my initiation, and whole progress in these Sciences), I upon occasion of speech told him of a Ruler of Numbers, Sines and Tangents, which one had

[1] G. Stokes, *The Slide Rule*, 1914.
[2] Cf. *New and General Biographical Dictionary*, 1784.
[3] Article *Slide Rule* in the *Penny Cyclopaedia* in 1842.

bespoken to be made (such is usually called Mr. Gunter's Ruler) 6 feet long, to be used with a payre of beam compasses. He answered that was a poore invention, and the performance very troublesome: But, said he, seeing you are taken with such mechanicall wayes of Instruments, I will show you what devises I have had by mee these many yeares. And first hee brought to me two Rulers of that sort, to be used by applying one to the other, without any compasses: and after that he shewed mee those lines cast into a circle or Ring, with another moveable circle upon it.[1] I seeing the great expeditenesse of both those wayes, but especially of the latter, wherein it farre excelleth any other Instrument which hath bin knowne, told him, I wondered that he could so many yeares conceale such usefull inventions, not onely from the world, but from myselfe, to whom in other parts, and mysteries of Art he had bin so liberall. He answered, That the true way of Art is not by Instruments but by Demonstration: and that it is a preposterous course of vulgar Teachers, to begin with the Instruments, and not with the Sciences, and so instead of Artists to make their Schollers only doers of tricks, and as it were Juglers: to the despite of Art, losse of precious time, and betraying of willing and industrious wits unto ignorance and idlenesse. That the use of Instruments is indeed excellent, if a man be an Artist: but contemptible, being set and opposed to Art. And lastly, that he meant to commend to me the skill of Instruments, but first he would have me well instructed in the Sciences. He also shewed me many notes, and Rules for the use of those circles, and of his Horizontall Instrument (which he had projected about 30 years before) the most part written in Latine. All which I obtained of him leave to translate into English, and make publique, for the use, and benefit of such as were studious, and lovers of these excellent Sciences.'

According to Oughtred's story, a right in the invention (as soon as it was settled to be published) was given to Elias Allen, a well-known Instrument-maker near St. Clement's Church, in the Strand. In walking to and fro from this shop, Oughtred also communicated his invention to one Richard Delamain, a mathematical teacher whom he used to assist in his studies.

Delamain appears to have already had some notion of the same kind in his mind, for without any loss of time

[1] Perhaps Delamain's invention.

he printed a tract on the new invention, describing it as a *Grammelogia* or *Mathematical Ring*, with an engraving of the instrument and instructions as to its use. He issued at least five different editions of the tract, which have recently been the subject of a valuable paper by Cajori.[1] The first impression is dated 1630, and he states that he first 'struke upon this conceit in February last' (1629). He obtained a patent for the sole Making, Printing, and Selling of the Instrument and Book, and advertised that

'This instrument is made in Silver, or Brasse for the Pocket, or at any other bignesse, over against Saint Clements Church without Temple Barre, by Elias Allen'.

After a few months, relations between Oughtred and Delamain became badly strained, and each roundly accused the other of having stolen his invention. Oughtred was angered that a mere 'Iugler' or 'doer of tricks', 'a pickpurse of another man's wit', as Robinson termed him, should have the 'malapert sawsiness' to claim his invention, and that with 'slaunderous insimulations'.[2]

W. Forster's work was republished in 1660 by A. H. (Arthur Haughton, another pupil of Oughtred), with Oughtred's consent, but the dedication and epistle were omitted.

A fine example of Oughtred's Slide Rule scales is preserved in the Library of St. John's College.

The oldest known Slide Rule

63. Oughtred's Circles of Proportion. **1632.**
With his **Horizontal Instrument.**

Diameter 1 foot 6 inches. St. John's College.

This fine instrument is inscribed with the name of

[1] *History of Gunter's Scale and Slide Rule during the seventeenth century. Univ. California Publ. in Mathematics*, i, 1920. We regret that a mistake in the identification of the book accompanying the instrument has led Prof. Cajori to refer the presentation of the instrument to St. John's College to 1660 instead of to the correct date, 1635. See his note on p. 209 of his *History*.

[2] Oughtred, *Apologeticall Epistle*, publ. separately in 1633 and also at the end of W. Forster's translation.

the maker, *Elias Allen fecit*, and with the name of the donor—

GEORGIVS BARKHAM; FILIVS D. IOHANNIS
COMMENSALIS; BARKHAM S. T. P.
DONO DEDIT A° 1635
(Coat of Arms)
(Motto) RECTA CERTA

Unfortunately all the movable parts excepting a couple of thumb-screws were missing when Mr. Stevenson first handed me the instrument for examination.

The face of the instrument is engraved with Oughtred's *Horizontal Instrument.* The back is engraved with eleven Circles as described in the '*Circles of Proportion and the Horizontal Instrument.* Both invented and the vses of both Written in Latine by Mr. *W. O*[ughtred]. *Translated into English and set forth for the publique benefit by* William Forster. LONDON. *Printed for Elias Allen maker of these and all other Mathematical Instruments, and are to be sold at his shop over against St Clements church with out Temple-barr.* 1632,' a copy of which was presented to St. John's College by George Barkham, to explain the use of the instrument in 1638.

At first we imagined that it might have once formed part of an astrolabe, but a preliminary cleaning revealed the circular logarithmic scales which gave me the clue to the real use of the instrument. Search among mathematical books of the period at Christ Church then introduced me to the work of Oughtred, and finally the finding of a copy of Forster's book at St. John's, inscribed with the name of the donor of the instrument, absolutely corroborated the identification.

This instrument is probably the oldest Slide Rule now in existence.

In the 1633 edition of the *Circles of Proportion* there is an illustration showing five circles which correspond to the outer five of the eleven circles upon the St. John's instrument, and also inner hour, calendar, and star circles which are omitted in the instrument, their place being taken by an orthographic projection of the sphere with lines of declination for every degree, lines of longitude, and the ecliptic. In execution this planisphere resembles the more finely engraved planispheres printed and published by Guilielmus Blaev, dated 1624, and sold as

an appendix to the 1633 edition of the works of Adrian Metius, professor of mathematics at the Frisian Academy, upon whom the mantle of Gemma Frisius appears to have fallen.

The purpose of the planisphere is explained in *An Addition vnto the vse of the instrument called the Circles of Proportion, for the Working of Nauticall Questions,* printed in the 1633 edition of the *Circles of Proportion.*

Oughtred's Circles were read by two radial pointers (unfortunately missing in the St. John's instrument), attached to the centre of the concentric circles, each charged with a logarithmic scale. These pointers could either move round together, united by friction, or open and shut by the application of pressure: they were, in fact, a pair of compasses, laid flat on the circle, with their pivot at its centre.

Calling these pointers antecedent and consequent, to multiply A and B the consequent arm must be brought to point to 1, and the antecedent arm then made to point to A. If the pointers be then moved together until the consequent arm points to B, the antecedent arm will point to the product of A and B.

The following description of the uses of the instrument has been reprinted from William Forster's translation of W. Oughtred's *Circles of Proportion*, 1632, with the addition, in brackets ⟨ ⟩, of the extra matter added in manuscript to the copy of the book which was presented to St. John's College in 1638 by George Barkam. These MS. additions may be in the hand of Forster, the translator, or of Allen, the printer and publisher.

The first part of the book shows the use of the Circles on the First side of the Instrument, 'for the working of *Proportions both simple and compounded*, and for the ready and easie resolving of questions both in *Arithmetique*, *Geometrie*, and *Astronomie* by Calculation.

The Circles are described in Chapter I.

The *First,* or outermost circle is of *Sines,* from 5 degrees 45 minuts almost, vntill 90. Every degree till 30 is divided into 12 parts, each part being 5 min: from thence vntill 50 deg: into sixe parts which are 10 min: a peece: from thence vntill 75 degrees into two parts which are 30 minutes a peece. After that vnto 85 deg: they are not divided.

The *Second circle* is of *Tangents,* from 5 degrees 45 min:

almost, untill 45 degrees. Every degree being divided into 12 parts which are 5 min: a peece.

The *Third circle* is of *Tangents*, from 45 degrees untill 84 degrees 15 minutes. Each degree being divided into 12 parts, which are 5 min: a peece.

The *Fourth circle* is of *Vnæquall Numbers*, which are noted with the Figures 2, 3, 4, 5, 6, 7, 8, 9, 1. Whether you vnderstand them to bee single Numbers, or Tenns, or Hundreds, or Thousands, &c. And every space of the numbers till 5, is divided into 100 parts, but after 5 till 1, into 50 parts.

The *Fourth circle* also sheweth the *true* or *naturall Sines*, and *Tangents*. For if the *Index* bee applyed to any Sine or Tangent, it will cut the *true Sine* or *Tangent* in the fourth circle. And wee are to knowe that if the *Sine* or *Tangent* be in the *First*, or *Second circle*, the figures of the *Fourth circle* doe signifie so many thousands. But if the *Sine* or *Tangent* be in the *Seventh* or *Eight circle*, the figures in the *Fourth circle* signifie so many hundreds. And if the *Tangent* bee in the *third circle*, the figures of the *Fourth circle*, signifie so many times tenne thousand, or whole *Radij*. ⟨And yf the Tangent be in the Sixt circle, soe many times 100000.⟩

And by this meanes the Sine of 23°, 30′ will bee found 3987: and the Sine of it's complement 9171. And the Tangent of 23°, 30′ will be found 4348: and the Tangent of it's complement, 22998. And the Radius is 10000, that is the figure 1 with foure cyphers, or circles. And hereby you may finde out both the summe, and also the difference of Sines, and Tangents.

The *Fift circle* is of *Æquall numbers*, which are noted with the figures 1, 2, 3, 4, 5, 6, 7, 8, 9, 0; and every space is divided into 100 æquall parts.

This *Fift circle* is scarse of any use, but onely that by helpe thereof the given distance of numbers may be multiplied, or divided, as neede shall require.

As for example, if the space between 1|00 and 1|0833+ bee to bee septupled. Apply the Index vnto 1|0833+ in the Fourth circle, and it will cut in the Fift circle 03476+; which multiplyed by 7 makes 24333: then againe, apply the Index vnto this number 24333 in the Fift circle, and it will cut in the Fourth circle 1|7512+. And this is the space betweene 1|00 and 1|0833+ septupled, or the Ratio betweene 100, and 108⅓ seven times multiplied into it selfe.

And contrarily, if 1|7512 bee to bee divided by 7: Apply the Index vnto 1|7568 in the fourth circle, and it will cut in the fit circle 24333: which divided by 7 giveth 03476+. Then againe vnto this Number in the Fift circle apply the

Index, and in the Fourth circle it wil cut vpon 1|0833+ for the Septupartion sought for.

The reason of which Operation is, because this *Fift circle* doth shew the *Logarithmes* of Numbers. *For if the Index be applyed unto any number in the* Fourth circle, *it will in the* Fift circle *cut vpon the* Logarithme *of the same number, so that to the* Logarithme *found you præfixe* a Caracteristicall (*as Master* Brigs *names it*) *one lesse then is the number of the places of the integers proposed* (*which you may rather call the* Graduall Number). So the Logarithme of the number 2 will bee found 0·30103. And the Logarithme of the Number 43|6 will bee found 1·63949.

Numbers are multiplied by Addition of their Logarithmes: *and they are Divided by Substraction of their* Logarithmes.

For the use of Navigation are added two circles, the sixth and the seventh: and a small alteration in the fifth. For the *fifth circle* is here divided also into 50 parts: and is conceived to have *two circuits.* The *first circuit* is unto 50: The *second circuit* from 50 unto 100. Wherefore the *figures are doubly noted:* on the *neerer side* of the long lines of tenth divisions are set 10, 20, 30, 40, 50, for the *first circuit:* And on the *further side* of those lines are set 60, 70, 80, 90, for the *second circuit.* And the ten subdivisions in every one of those 50 parts are the D*ecimall parts* thereof.

The *sixth* and *seventh circles* are divided into degrees: and every degree into ten parts, containing 6 minutes, or rather 10 hundreth parts a piece, The *sixth circle* hath the degrees unto 44|5: and the *seventh circle* hath from 44|5 unto 70. And these degrees serve for so many severall *Latitudes*, or *Elevations of the Pole.*

The *Eight circle* is of *Tangents* from 84 degrees till about 89 degrees 25 minutes.

The *Ninth circle* is of *Tangents* from about 35 min: till 6 degrees.

The *Tenth circle* is of *Sines,* from about 35 minutes til 6 degrees.

In the middest among the Circles, is a *double Nocturnall* instrument, to shew the hower of the night.

The right line passing through the Center, through 90, and 45 I call the *Line of Vnitie*, or of the *Radius.*

That *Arme of the Index* which in euery Operation is placed at the Antecedent, or first terme, I call the *Antecedent arme:* and that which is placed at the consequent terme, I call the *Consequent Arme.*

⟨The first significant figure of a number is to be taken in

one of those nine figures in the spaces of the fourth circle: and the rest of the figures in the diuisions & subdiuisions following.⟩

⟨But note that for the vse of Nauigation there haue bene two circles inserted next w[th]in the fift circle; which are not in the scheme before pag: 1. Which make those innermost circles of Tangents & Sines to be the Eigth, Ninth, & Tenth.⟩ [This alteration in the enumeration has been adopted in the text.]

The *Horizontal Instrument* will be described under Sundials.

Later Slide Rules of the Seventeenth Century

During the second half of the seventeenth century spiral forms of the slide rule were devised. The earliest is attributed to Milburne, a Yorkshireman, by Hutton,[1] and another to T. Brown, who projected Gunter's line 'into a kind of spiral of 5, 10, or 20 Turns, more or less', and used 'flat compasses, or an opening index'.[2] Of Brown little is known, but Professor Cajori[3] conjectures that he may be the instrument-maker named by Pepys in his diary.

'Abroad to find out one to engrave my tables upon my new sliding-rule with silver plates, it being so small that Brown who made it, cannot get one to do it. So I got Cocker the famous writing master, to do it, and I sat an hour beside him to see him design it all, and strange it is to see him, with his natural eyes, to cut so small at his first designing it, and reading it all over, without any missing, when, for my life, I could not with my best skill, read one word or letter of it' (10 Aug. 1664). 'On the next day comes Cocker with my rule, which he hath engraved to admiration for goodness and smallness of work. It cost me 14s. the doing.'

Passing over the writings of Seth Partridge (1603–1686, *D.N.B.*), a teacher of mathematics of no great originality, we come to the men who adapted the Slide Rule to the practical solution of various problems of Gauging. Among those who continued the work of Oughtred and Allen for this purpose were Coggeshall, Thomas Everard, and Hunt.

[1] Art. 'Gunter's Line' in *Philos. and Math. Dictionary*, London, 1815.
[2] Stone, *Mathematical Instruments*, p. 16, London, 1723.
[3] *History of the Logarithmic Slide Rule*, p. 16, 1909.

Indeed, before the claims of Oughtred were pointed out, the original invention of the first slide rule was attributed to Everard in 1683 when he was an Officer in the Excise at Southampton.

1677 COGGESHALL's Slide Rule was for measuring timber, stonework, and vessels. It is described in the following works:

Henry Coggeshall, *Timber Measure by a Line of more Ease, Dispatch, and Exactness than any other way now in use, by a Double Scale.* London, 1677.

Treatise of Measuring by a Two-foot Rule, which slides to a Foot. 1682.

The Art of Practical Measuring easily performed by a Two-foot Rule, which slides to a Foot. 1722.

The Coggeshall slide rules were much used all through the eighteenth century and even in the nineteenth.

1683 EVERARD. His rule was made by Isaac Carvar of Horsleydown near London,[1] and is described in his work on *Gauging*, and again in Stone's *Bion*, 1723, p. 22, see below.

1697 The next contribution of importance to the subject was W. HUNT, *A Mathematical Companion, or the Description and Use of a New Sliding-Rule, by which many Useful and Necessary Questions in Arithmetick, Interest, Planometry, Astronomy, Fortification, Dialling, &c., may be speedily resolved, without the help of Pen or Compass.* 1697.

In Hunt's instrument there was a line of segments, by which the area of a segment of a circle may be found, as described on pp. 168-9 of his book.

MAKERS AND IMPROVERS OF SLIDE RULES DURING THE EIGHTEENTH CENTURY

JOHN WARNER, a London dealer in instruments.

CHARLES LEADBETTER, *Royal Gauger*, p. 27, 4th edit., 1755. Suggested an Improvement on Everard's Slide Rule. Leaving lines A, B, C, D, E, MD,[2] as before, Leadbetter puts the SL and SS lines on one of the narrow faces, and between them a third slider, narrower than the other two sliders. There were only two sliders in the early Everard rules. This new slider carries a line of numbers of double radius marked *N*. Another innovation are lines of inches and other lines, placed upon the back sides of the three sliders (Cajori, p. 29).

ROBERT SHIRTCLIFFE, *Theory and Practice of Gauging*, 1740.

[1] Leadbetter, *Royal Gauger*, p. 80, 1755.
[2] MD = Malt depth.

Several drawings of slide rules. He suggested the new line SR, which was executed by the instrument-makers Coggs and Wyeth.

Mr. John Rowley of Fleet Street made a Five-Foot Rule with a sliding part, for John Ward, *The Young Mathematician's Guide . . . with an Appendix on Practical Gauging*, 1707, pp. 450–1.

J. Vero, 'sometime a Collector in the Excise made an Alteration in Everard's Sliding Rule, so that the whole Length of one foot contained by one single Radius of the Line of Numbers, and both Sliders do work together on one Side of the Rule in every operation; by which contrivance the Divisions in this Rule are twice as large as on those first made by Mr. Everard'.[1]

'Ios Saxspeach Invt Ratcliff Ianuary 1753 . Ben . Parker Fecit' is the inscription on a special Slide Rule, containing a telescope, with two separate sliders at the sides. Size $12 \times 1\frac{13}{16} \times \frac{7}{8}$ inches. (L. E. coll.)

John Robertson (1712–1776). Librarian of the Royal Society, published in 1775 a *Treatise on Mathematical Instruments*—and left an account of a modified slide rule which was published after his death by William Mountaine, *A Description of the Lines drawn on Gunter's Scale, as improved by Mr. John Robertson*, London, 1778.

Robertson's improved Gunters were made under his own inspection by Messrs. Nairne and Blunt of Cornhill. The new instruments were called Sliding Gunters, a term which had already been used by Stone in 1723. A runner was used for the first time.

Among the early nineteenth-century makers of slide rules should be mentioned Rooker of Little Queen Street, who made Roget's Sliding Rule (*Phil. Trans.*, 1815) and Woolgar's Pocket Calculator, *c.* 1830; Cary of the Strand, who made Bevan's Engineer's 12-in. Rule; and Jones of Holborn, who made Henderson's Double 12-in. Slide Rule.

63. 9-inch Sliding Gunter. c. 1710.

Ivory. Orrery coll.

Inscr.: I: Rowley, fec.

The lines put upon it are M (=Meridian line), S (=sines), T (=tangents), EP (=equal parts). The M scale and its uses are described in Gunter's works.

[1] Leadbetter, *Royal Gauger*, p. 29.

64. Everard's Slide Rule for Gauging. **18th cent.**

Length 18 in. Ashmolean Museum.

Side 1. Marks *A*. M^rs. B. MB [= Malt Bushel].
Side 2. ,, *B*. (Slider) W [= cu. inches in a Wine Gallon. C [= Circumference of a Circle whose diameter = 1].
,, *C*. (Slider) ⊙c [At 0·795 = Area of a Circle whose Circumference = 1].
,, *D*. WG [= Wine Gallon]. MS [= Side of a square whose content = inches in a solid Bushel].
Side 3. Inches divided in $\frac{1}{10}$ths.
Foot ,, $\frac{1}{100}$ths.
Side 4. 'Spheroid' 'Variety'. [A line by means of which, and the line of inches, the mean diam. of the Cask is the figure of the middle frustum of a Spheroid.]

The use of Everard's Slide Rule is explained in Stone's *Bion*, p. 22.

'This Slide Rule and all sorts of Instruments useful in Gauging, Surveying, Dialling, and all parts of the Mathematicks are made to the greatest Exactness and sold at the most reasonable prices by *John Fowler* at the Globe in Sweeting's Alley by the Royal Exchange, London.'

[Advt. in T. Everard's *Stereometry*, 10th edit., 1738.]

65. Excise Officer's Scale for calculating Wine and Spirit Measure.

University Observatory.

Inscr.: Joseph Stutchbury, Maker, Dove Court, Old Jewry, Lond.

66. Excise Officer's Slide Rule. **18th cent.**

2 ft. 6 in. long. Radcliffe Observatory.

Inscr.: Nairne & Blunt, London.

'S. Rum, T. Rum, V. Sin' with screw fine adjustment.

67. Ditto. **18th cent.**

25 in. long. Radcliffe Observatory.

68. Slide Rule for Sines and Cosines. **c. 1820.**

University Observatory.

Inscr.: 'Roget, Sec. R. Soc. inv^t.' By Rooker.

Peter Mark Roget, M.D., F.R.S., the author of the

well-known Thesaurus of English Words, lived *c.* 1800–50.

69. Slide Rule for Money Exchange. 'Ap. 24, 1815.'

Radcliffe Observatory.

Inscr.: W. Cary 182 Strand.

GAUGING INSTRUMENTS

70. Excise Officer's Measuring Rod and Scale on a Walking Stick.

Ashmolean Museum.

Inscribed with the name of owner, 'Absalom Leech'. The handle is contrived as a Pillar Dial, to be described in the section on Sundials.

Head rod. For ascertaining the head diameter of a cask, and working out the contents.

Bung rod and slide For finding the bung diameter and diagonal of a cask. The rod is divided into inches and tenths with a line of imperial area and diagonal line; this last gives the approximate contents without calculation, and is computed on the assumption that most casks are similar to one another in form, and therefore vary as the cubes of their like dimensions.

71. Scale of Atomic Weights.

Radcliffe Observatory.

Inscr.: I. Newman, 122 Regent Street, London.

STANDARD MEASURES

Until the passing of the Act of 5 & 6 Will. IV, c. 63, under which the inspection of Weights and Measures was vested in Inspectors appointed under the Act, it was the duty of the Clerk of the Market in Oxford to try all weights and measures within his jurisdiction, whether they be of the true standard or not. Early in the history of the University, *c.* 1268,[1] the Assises of weights and measures, as well as the Clerkship of the Market, were assigned to the University; and the original grant to the University 'for the correction of Weights and Measures' was renewed from time to time by the

[1] *Oxf. Hist. Soc., Collectanea*, ii, p. 47.

King. In early days the Chancellor himself appears to have administered the office of Clerk of the Market, for there is a list of his belongings, dated 1427, which included three bronze measures for corn, viz. a bushel, a half-bushel, and a quarter-bushel, and four bronze measures for liquids, viz. a lagena (= flagon [1]), a potella (= half-gallon), a quart, and a pint: two sets of brass weights of which one was of the weight of 16 marks troy weight,[2] and was used for weighing bread and money, the other was of 4 pounds, popularly called the 'Lygging weight', and was used for weighing spices and candles: two balances: a rod of gilt brass for measuring cloth: two iron seals, one for sealing wooden measures for grain, and the other for sealing pots, and measures for wine and beer, and lead weights of millers or bakers and others; and the seals are in the form of a bull's head.

The first statute embodying the duties of Clerks of the Market defines one duty as the taking care 'ne qua fraus in mensuris et ponderibus . . . committatur'. (*Statute of* 1556.)

Orders of the Market of Oxford, dated 1579, are of capital importance in the history of our subject, and we note with pleasure that they were drawn up when a man of science became Vice-Chancellor. Martin Colepeper, Doctor of Physick, noted that 'divers in this Cittie of Oxford & suburbes of the same haue bene sundry tymes grevously complayned vpon for vniust & unlawfull weightes, measures & yeardes to the great infamye & reproch of the saide Citie and also of this Vniuersitie vnto the which the reformacion thereof apperteyneth. Nowe the saide Vicechauncellor to take cleane away as neere as may be the cause of all such obloquye & iust complaint for the same; hath to the great Charges of this Vniuersitie and trauaile of some therevnto chosen & appointed (through the speciall good meanes of the right honorable the Earle of Leycestre Chauncellor of this saide Vniuer-

[1] According to an Assise of David, King of Scotland, a Lagena ought to contain 12 pounds of average water, viz. 4 pounds of sea-water + 4 pounds of lake water + 4 pounds of clear running water. The standard vessel ought to be $6\frac{1}{5}$ inches deep, $8\frac{1}{2}$ wide below, the circumference should be 27 inches at the top and 23 inches at the bottom (Ducange).

[2] A mark = 8 ounces.

sitie procured a perfitt standerd of all weightes & measures, for the tryall of all other weightes & measures, And prepared a convenient place in St. Maries to keepe the same, whereunto men may haue convenient accesse to try theires. And therefore he precysely & strictly chargeth & Commaundeth that all weightes as well Troye as Auer de pois, all measures for graine as busshells, half bushells, peckes and halfe peckes, All measures for wine to be sould by retaile as gallons, pottells, quartes, pintes & halfe pintes: And all measures for ale and beere to be sould by retaile as gallons, pottells, quartes, pintes & halfe pintes: And all kind of meate yardes for wollen lynnen, silke &c. and all other measures (onlye brueres measures as barrells, kilderkins, firkins, Runlettes, Ludemeales, gallons excepted) which are & may be more conueniently tryed at their houses, to be brought into the place appointed for the same purpose at St. Maries aforesaid, then to be viewed, tryed & sised, allowed and sealed betweene the first daye of the moneth of June and the xxiijth day of the same moneth next followinge this present proclamacion 1579, which respit of time the saide vicechancellor graunteth, for that his meaninge is not to seeke the extremitie of lawe; vppon any th' offendors in the premisses for any fault heretofore commytted so that the same within the saide tyme be reformed without fraude. But from henceforth all such as shallbe found to haue vnlawfull weightes, measures, or yardes, to be punished severely accordinge to dyvers statutes of this Realme in that behalfe provided.'[1]

The document is of interest because it tells us that the Standards were kept in St. Mary's Church and that the Inspection took place there.

Measures of Length

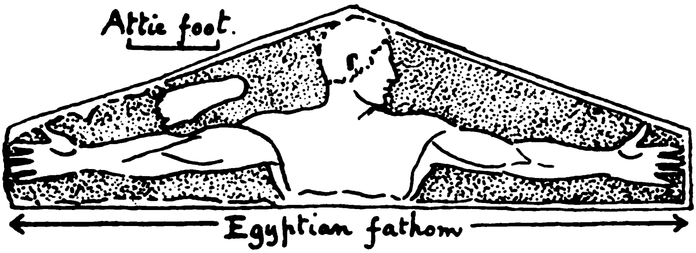
72. Standard Measures of the Samos Fathom and Foot. 5th cent. B.C.

Ashmolean Museum.

A marble bas-relief of a man with arms outstretched, and of the imprint of the sole of a foot. Michaelis held the view that this metrological relief combines the units

[1] Twyne's MSS. 16, 41, 42.

of two different countries, Greece and Egypt. The foot is the Attic foot of 11·6 inches, of which seven go to



make one Egyptian fathom of 81·5 inches. (*J. Hell. Studies*, iv.)

Chain Measures

'The Chains now used, and in most esteem among Surveyors, are Three: as, First, Mr. Rathborn's which had every Perch divided into 100 Links: and that of Mr. Gunter's, which had 4 Perches or Poles divided into 100 Links: so that each Link of Mr. Gunter's Chain is as long as four of Mr. Rathborn's. And this year [1669] Mr. Wing hath described a Chain of 20 Links in a Perch, for the more ready use in his Art of Surveying.'

73. Gunter's Chain. **16—.**

Christ Church.

'Master Gunter's Chain is a Chain most used amongst the Surveyors of this Age, and is always made to contain 4 *Poles*, and each *Pole* 25 Links, and each Link 7 Inches $\frac{92}{100}$ of an Inch.' Samuel Sturmy, *Mathematical and Practical Arts*, v, p. 3, 1669.

Graham's Brass Standard Yard and Diagonal Scale by Sisson. **1742.**

Described in the *Phil. Trans.*, xlii, p. 185.

No. 41. Royal Society.

In Science Museum, S. Kensington.

Standard Scale, Brass. By Bird. **c. 1750.**
Pres. by Bird's exors.

Phil. Trans., 1798, p. 177. No. 42. Royal Soc.

In Science Museum, S. Kens.

Standard Scale of Sir George Shuckburgh Evelyn.

Phil. Trans., 1798, p. 137. No. 43. Royal Soc.
In Science Museum, S. Kens.

Standard Mètre à bouts. By Fortin.

Phil. Trans., 1818, p. 103. No. 44. Royal Soc.

Standard Mètre à traits. By Fortin.

Phil. Trans., 1818, p. 104. No. 45. Royal Soc.

Imperial Standard Yard. Copy by Dollond.

Phil. Trans., 1831, p. 345. No. 46. Royal Soc.
In Science Museum, S. Kens.

74. Standard Yard and Metre. **c. 1865.**

University Museum.

Yard of 5 George IV, c. 74.
Metre of 27-28 Victoria, c. 117.
On porcelain by I. Casella. No. 21. Published by the Metric Committee of the British Association.

Standard Measures of Capacity

Only one of the Oxford Measures, the bronze Bushel of 1601, represents to us the great beauty of the early Standards. From the artistic point of view they have steadily deteriorated, and doubtless without gaining in scientific accuracy.

75. Bushel. Bronze. **1601.**

Diameter 20 inches. Ashmolean Museum.

Inscribed:

ELIZABETH (*Rose*) DEI GRACIA ANGLIAE (*Portcullis*) FRANCIAE ET (*Fleur-de-lis*) HIBERNIAE REGINA. 1601. (E·R).

A new set of standards was provided in 1670, and in the same year Peter Mews the Vice-Chancellor issued a citation to the Assise of Weights and Measures, requiring all persons inhabiting within the Precincts of the University, that use or have any 'Weights or Measures, greater or less, sealed or unsealed', to bring them before the said V.-C., or before the Clerks of the

NOS. 75 AND 76. STANDARD MEASURES

77 78 84 85

80 81

82 83

79 81

NOS. 77-85. STANDARD MEASURES

Market 'to St. Mary's Church in Oxon: there to be examined and reviewed with the publick standard, upon such severall days as are underneath expressed. Hereof fail you not'.

76. Bushel. **1670.**

Diameter $19\frac{1}{2}$ inches. Ashmolean Museum.

Inscribed:

UNIVERSITAS OXON. T.T

77–8. Ale quart and pint. **1670.**

Inscribed with name of measure and stamped with letters C·R under a crown.

79. Peck. No date.

Diameter $14\frac{5}{8}$ inches. Ashmolean Museum.

In 1701 the Vice-Chancellor ordered, 'That no person whatsoever presume to sell or utter any Wine, Ale, or Beer, in any Potts or Vessels, saving only such as are of lawful Measure, according to the several Standards, Seal'd, Stampt, and allowed'. In 1737, during the Clerkship of M. Beaver (Superior Bedell in Civil Law), a new set of Measures was provided.

80–83. Wine gallon, quart, pint, and half-pint. **1737.**

Diameter $7\frac{1}{2}$ inches to 3 inches.

Each of the vessels is stamped eight times on the rim, four times with a G under a crown and four times with daggers.

84–5. Ale quart and pint. **1778.**

Marks: W·R under a crown and a part of a chess-board.

These old standard measures were all deposited in 1866 by the Registrar of the University in the Ashmolean Museum.

Weights

Standard Weights by Read. **1742.**

No. 41. Royal Soc. In Science Museum, S. Kens.

Imperial Unit Pound of the House of Commons. 18—.

No. 48. Royal Soc.

Copy by Capt. L. von Nehus of the Royal Observatory, Altona.

Measurement of Angles

The Division of an Arc of a Circle

The division of an arc of a circle into a number of degrees of correct value, and all equal to one another, is by no means an easy task. Nor are the best methods the invention of any one man, or of a day. The classical instance exhibited by an Oxford instrument is the work of Bird in the Radcliffe Observatory, to which we shall refer more fully in the description of the instrument.

Limb of 8-foot mural Quadrant. 1772.

Radcliffe Observatory.

By Bird.

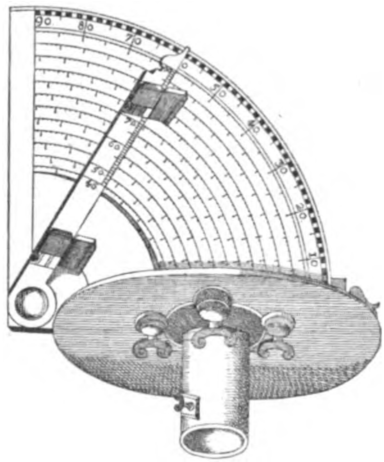
Small Angles

Various expedients have been adopted to secure accuracy in the measurement of very small angles. The Arabians constructed their observatory-quadrants and sextants on such a gigantic scale that, it is said, they were able to read directly to six seconds of arc. But in the case of portable instruments increase in size defeats its own object, for the apparent greater refinement of the readings is more than counterbalanced by the errors due to frame-flexures in the instrument itself.

The Nonius

Pedro Nunez (1492–1577), *De Crepusculis*, 1542, a Portuguese of the University of Coimbra, was the first to show how an arc upon an instrument of moderate size might be subdivided with some degree of accuracy by drawing 44 arcs inside and concentric with the graduated arc of a quadrant. The outer arc being graduated into 90 degrees, the inner arcs were to be divided respectively into 89, 88, 87, &c., and 46 equal divisions, so that the alidade in any position would (more or less

accurately) touch a division-mark on one of the 45 circles. Suppose the 45th division on the arc divided into 50 parts to be the division touched, then the angle is $\frac{45}{55}$ of 90 degrees, equal to 73° 21′ 49″. The *Nonius*, as this device was called, is figured in a simple form in the Quadrant shown in the figure.



THE NONIUS APPLIED TO A QUADRANT.
(*From Dudley's 'Arcano del Mare'.*[1])

Tycho graduated his two smallest quadrants and a sextant according to the plan of Nunez, but abandoned it again as more cumbrous than the one he subsequently adopted, namely, that of transversals.

'By a strange misunderstanding the name of Nonius is even at the present day often applied to the beautiful invention of Pierre Vernier (1631), with which it has nothing in common.'

A further complication in the history of inventions is also due to the fact that the *Vernier* itself is said to have been suggested to Tycho Brahe in 1590 by Jacque Curtius, but there is no evidence that the idea was put into practical operation before Pierre Vernier took it in hand in 1631.

[1] Block from Reeves's *Maps*, lent by the Royal Geographical Society.

Transversals

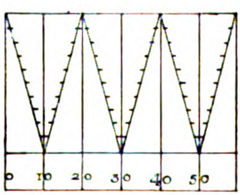
Dr. Dreyer has collected some historical notes upon the application of transversals to the subdivision of the graduated arcs of astronomical instruments. Several names have been mentioned in connexion with the invention, and we have in Oxford a very early example of their application on an instrument of 1579.

Tycho obtained a cross-staff divided by transversals, 1564: Homilius, *d.* 1562, instructed Bartholomeus Scultetus in their use, but the latter [1] stated that the method was known to Purbach and Regiomontanus.

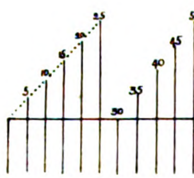
'We can, however, scarcely believe this to have been the case, as it would be difficult to explain why the method had never come to light, even though Walther notoriously guarded the belongings of Regiomontanus with a curious fear of their being known.'

But the Method is also said to have been described in Puchler's Geometry, published in 1561.[2]

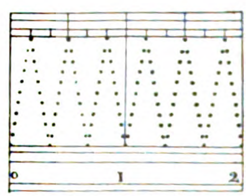
And in 1573 Digges [3] actually gave a drawing of a rectilinear scale with transversals, which he says were first applied to the divisions on the cross-staff by the English instrument-maker Richard Chanzler.



1573.
From Digges's 'Alae'.



1579.
From Schissler's Quadrate.



1602.
From Tycho Brahe.

Transversals on Quadrate. **1579.**

Bodleian Library.

By C. Schissler of Augsburg.

It will be noted that the transversal lines of dots all

[1] *Von allerlei Solarien . . .*, Gorlitz, 1572, quoted by R. Wolf, *Astr. Mitth.*, xxxiii, p. 90.
[2] Kästner, *Gesch. der Math.*, iii, p. 479.
[3] *Alae seu scalae mathematicae*, London, 1573.

slope in the same direction, whereas Tycho adopted a zigzag arrangement. We believe that the straining after instrumental precision characteristic of this period had been suggested by the greatly elaborated tables recently calculated by Purbach and Regiomontanus, which would have been useless without observations made by instruments of corresponding accuracy. It is possible that Schissler learnt the advantage of the oblique lines of dots from some contemporary instrument-maker at Augsburg, possibly from Paul Hainzel, who is reported to have graduated to 10 seconds of arc instruments which may have been among those used by Tycho Brahe.[1]

The earliest example of Tycho's method is the scale on an Azimuthal Quadrant of 1577—only two years before the date of Schissler's work, but no account, so far as we are aware, was published, before the appearance of his *Astr. Instr. Mechan.* in 1602. This method of oblique lines of dots was also used in 1604 by Henry Hofmann for graduating an Octant, a print of which was engraved by George Haÿer in that year.[2]

Tycho Brahe, like Schissler, did not use transversal lines such as afterwards became universally used, but rows of dots, which were fully as convenient. He showed that the error introduced by employing these rectilinear transversals for the division of arcs would not exceed 3″, which would be imperceptible. When Wittich had brought the news of this contrivance to Cassel, Bürgi modified it a little by using lines instead of rows of dots.[3]

I was very pleased to find in the Evans collection an early instrument dated 1608 in which lengths of $1\frac{1}{4}$ inches were divided into 100 equal parts by transverse rows of dots, sloping one way only, and to all intents and purposes similar to the Transversals on Schissler's Quadrate.

[1] All who strive after the utmost precision in the use of instruments without that mead of sympathy which they consider due from their contemporaries, may remember that the life work of their great predecessor in accuracy, Tycho, was judged by a Commission to be 'not only useless, but noxious'.

[2] Hofmann, *De Octantis*, Jena, 1612.

[3] Joost Bürgi, b. 1552, court watchmaker at Cassel, 1579, mechanician to the Landgrave of Hesse (fl. 1580) who introduced pendulums for controlling clocks.

Like it, the instrument was of gilt-brass, by a maker signing himself 'C. T. M. F. 1608'.[1]

In an early Surveying Semicircle of Dutch or Flemish make in the same collection, the degrees are divided into halves, and each half is again divided into $\frac{1}{5}$ths by transversal rows of dots.

A step towards the idea of Vernier was made by Christopher Clavius (*Opera*, 1612, t. iii, p. 10).

The Vernier

The earlier device of diagonal lines on scales and instruments designed for very accurate measurement has now been generally superseded by a simple contrivance which takes its name from its inventor, Pierre Vernier, who, in 1631, published a paper describing the invention and its application to the Quadrant.[2] In the original instrument 30 of the divisions of the vernier scale were equal to 31 of the divisions of the quadrant scale which was divided into half-degrees. The degrees and half-degrees were read from the quadrant and the remaining minutes from the vernier.

Micrometer

If the Nonius and the Vernier are to be put to the credit of Portugal and France respectively, the Micrometer microscope is to be regarded as an English invention. For it was Gascoigne, a young astronomer who fell at Marston Moor, who first suggested the great accuracy of this instrument.

The first micrometers were adapted for use with astronomical telescopes. A very early example is contained in the Orrery collection at Christ Church. It is fitted to the eyepiece of a telescope.

In the eighteenth century Ramsden fitted micrometers to his theodolites, but it is only within the last half-century that they have been fitted to ordinary surveyor's theodolites.

[1] I suggest, as a guess, that this inscription might stand for *Christof Tressler mechanicus fecit*.

[2] P. Vernier, *La Construction, l'Usage, et les Proprietez du Quadrant nouveau de Mathematique*, 1631. See also the article 'Vernier' in the English Cyclopaedia.

NOTES ON MATHEMATICAL INSTRUMENT MAKERS

The names are arranged in chronological order. Makers of sundials and special instruments will be referred to in the sections dealing with their instruments.

In or before 1650, John Pell, D.D., formerly Professor of Mathematics at the Prince of Orange's illustrious school at Breda, put pen to paper and wrote *An Idea of Mathematics* which was transmitted to Samuel Hartlib and printed in John Durie's *Reformed Librarie-Keeper*, p. 33. According to Pell, the eighth duty of 'a Librarie-keeper of great judgment' is

> 8. To keep a Catalogue of all such workmen as are able and fit to bee imploied in making Mathematical Instruments and representations, working upon Wood, Magnets, Metals, Glass, etc.

The present author, having accumulated these few notes before he became a Librarian, now publishes them in the hope that Pell's idea may soon be carried out on an amplified scale.

A few names of the more prominent instrument-makers of the sixteenth century are contained in MS. notes by Gabriel Harvey, the poet, in his copy of Blagrave's *Mathematical Jewel* in the British Museum. One note, *c.* 1585, relates to the Jewel: 'Mr. Kynvin selleth ye Instrument in brasse.' A later note refers to Blagrave's Staff: 'His familiar Staff newly published in 1590. The instrument itself, made and solde by Mr. Kynuin of London, neere Powles. A fine workman & mie kinde frend: first commended unto me bie M. Digges & M. Blagrave himself. Meaner artificers much praised bie Cardan, Gauricus & other, then He & old Humfrie Cole mie mathematical mechanicians. As M. Lucar newly commendes Jon. Reynolds, Jon. Read, Christopher Paine, Londoners, for making Geometrical

Tables, with their feet, frames, rulers, compasses & squires, M. Blagrave also in his *Familiar staff* commendes Jon. Read, for a verie artificial workman.'

Information of great value is contained in the papers of JOHN COLLINS (1625–82), who, though not a member of the University, was in close touch with those who were. He was born in 1625 at Wood Eaton within five miles of the city of Oxford, and at the age of sixteen was apprenticed to Thomas Allen, a bookseller living outside the Turl Gate. He became an F.R.S. in 1667, and was referred to by Wood as 'a person of extraordinary worth'. For a time his occupation was that of Accountant to the Excise: his hobby was that of 'attorney-general of the mathematics, who wrote to everybody, heard from everybody, and sent copies of everybody's letter to everybody else'. (De Morgan.) Many of Collins's letters and other manuscripts are still in Oxfordshire in the library of the Earl of Macclesfield at Shirburn. A selection of these papers was made by Rigaud, and was printed by the Clarendon Press, but there still remains at Shirburn a valuable mass of non-epistolary manuscripts which have passed into the possession of the present Earl, by inheritance from his great-great-great-grandfather, and are unfortunately not accessible to students.

The ORRERY COLLECTION gives us in Oxford a unique insight into the work of the better Instrument Makers of the period 1690–1710. It came to Christ Church in 1731 as part of the bequest of CHARLES BOYLE (1676–† 1731), 4th Earl of Orrery, and great-nephew of Robert Boyle (1627–91), who had been up at the House from 1690 to 1694. The collection contains numerous examples of the work of Rowley, Worgan, Sutton, Marshall, and other makers, made for a wealthy patron, who appears to have been an amateur astronomer and a knowing man in the use of tools.

Half a century later, in 1758, the state of the instrument market is well described for us by Edward Stone in the preface to the *Supplement* to his English *Bion*. He notes that many French instruments were excelled by those of English make. He 'never did see one French Instrument so well framed and divided, as some of ours have been; for example Mr. SUTTON's Quadrants,

made above one hundred years ago, are the finest divided Instruments in the World. The mural Quadrant at the Royal Observatory at Greenwich, far exceeds that of the Royal Observatory at Paris. Also the Theodolites of Mr. SISSON and HEATH, the Clocks and Watches of Mr. GRAHAM, TOMPION, and QUARE, the Orreries of Mr. GRAHAM and Mr. WRIGHT' all come in for their share of commendation.

HUMPHREY COLE.

The most famous of the Elizabethan instrument makers.

A book of gilt-brass consisting of five parts hinged together, now in the possession of my friend Mr. Lewis Evans, is the earliest example of his work.[1] It is inscribed

Humfray Coole made this boke anno 1568.

In 1569 he made the instrument known as Drake's Pocket Dial.

1579. Horizontal Sundial, marked H. Cole + + 1579 + (L.E.)

The latest record of his work is dated 1582, and belongs to Mr. G. H. Gabb.

JAMES KYNUYN.

1585. Blagrave's Mathematical Jewel.
1590. „ familiar Staff.
1593. Dial for Robert Devereux, Earl of Essex. (*Archaeologia*, xl.)

BARTHELMEWE NEWSUM.

Clock and dial maker to the Queen, of the Strand, died 1593. One of the earliest makers of portable clocks, whose work survives. Maker of a beautiful case of mathematical instruments (including a beam compass), two of which are represented in the figure on p. 47.

[1] I am obliged to Mr. Evans for this and for all other information quoted over the initials L.E. His collections of instruments is perhaps unrivalled as a private collection in England, and how generously he places his great stores of information at the disposal of those interested is known to many workers besides myself.

The case, of gilt-brass, is figured in *Archaeologia*, lv, p. 531. It is the property of Dr. English of Sleights, Yorks. Among the tools mentioned in Newsum's will (1586) are a 'best vice save one' and a 'beck-horne to stand on a borde'. (Britten, *Clock and Watch Makers*, 1894.)

CHAROLUS WHITWELL.

1593. Gilt Sundial invented by Nath. Torporley, in L. Evans collection.
1597. An instrument by him at Florence.
1598. Sector. 'The Instrument is made by Charles Whitwell dwelling without Temple Barre, against St. Clements Church.' (Th. Hood, Dr. in Phys., *The Making and vse of the Geometricall Instrument called a Sector*, 1598.)
1606. Dial (acquired at Norwich). (L.E.)

IOHN TOMSON.

1610. 'You may have any of the Instruments in this book made of wood, in Hosier lane, neere Smithfield in London, by Iohn Tomson.' (A. Hopton, *Baculum geodaeticum*, 1610.)

A copy of this work in the Library of Shrewsbury School contains a printed label, 'The gift of the Author to the Schoole of Shrewsbury being sometime a schollar there'.

J. READ, *c.* 1650.

Lived in Hosier Lane with or after J. Tomson, q.v.

CASPAR KALTOFF.

1626. Engaged by Edward Somerset, 6th Earl of Worcester, as a skilled mechanic, to work in a house at Vauxhall, that was designed as a 'College for Artisans'.

No specimens of his work are known to me.

ELIAS ALLEN.

1606–11. At Blackhorse Alley, Fleet Bridge. (L.E.)
1611. Maker of the *Topographicall Glasse*. 'The Glasse is made in brasse in blacke Horse-ally, neere

Fleetebridge by Elias Allin.' (Arthur Hopton, *Baculum geodaeticum.*)

'A man well knowne and esteemed by all men of art for his skilfulness in making instruments in metal.' (Wm. Oughtred.)

1631–2. By St. Clements Church without Temple Bar.

1633. Maker of Oughtred's measuring rods or gauging rods.

'These Instruments are made in brasse by *Elias Allen* over against St. *Clements* Church without Temple-barre: where also those who are desirous may bee instructed in the practicall use thereof: and such as shall have occasion may have their vessels gauged.'

Advertisement at the end of the description of Oughtred's *New Artificial Gauging line or Rod,* London, 1633.

1635. Maker of Oughtred's Horizontal Dial at St. John's College.

1652. Maker of 'Instrumentall Dials in brasse, dwelling over against St. Clement's Church without Temple Barre, at the signe of the Horseshooe neere Essex Gate'. (W. O[ughtred], *Descr. of Double Horizontall Dyall.*)

1654. Died: buried at Ashurst, Kent, where he gave a sundial in 1643. (L.E.)

John Allen.

A nine-inch Sector marked 'John Allen fecit', but not dated. (L.E.)

Richard Delamain.

Lived in the 'Upper part of Chancery Lane'. See p. 64.

Ralph Greatrex, *c.* 1660.

Mathematical instrument-maker, a great friend of Oughtred.

Christopher Brookes.

'Mathematique Instrument Maker, and *Manciple* of Wadham College in Oxford'; author of *The Solution*

of all Sphaerical Triangles, both right and oblique by the Planisphere, 1651. 'And to be had at . . . and at Wadham College.'

'An exact workman in his trade of making mathematical instruments in metal', he was probably employed by Seth Ward. He married a daughter of William Oughtred. (Letter from Oughtred, in Aubrey, *Lives*.)

FRANCIS POTTER (1594–1678).

Commoner of Trinity College 1609, M.A. 1616, B.D. 1625; succeeded his father, Richard, as Rector of Kilmington, 1628. A practical mechanician; inventor of a graduated compass; maker of quadrants, dials, and an instrument for drawing in perspective; a transfuser and an experimenter with bees. (*D. N. B.*)

HENRY SUTTON.

Designer and maker of Quadrants, 1656–69.

AN ADVERTISEMENT.

All manner of Mathematical Instruments, either for Sea or Land, are exactly made in Wood or Brass, by *Henry Sutton, in Thredneedle* Street, near *Christophers* Church, or by *William Sutton* in Upper *Shadwel*, a little beyond the Church.

1659. Planisphere of brass with a horizontal projection of the sphere 15⅜ inches in diameter. At the sides of a tabular Calendar for 1660–1712 is inscribed

Henrici Sutton Londini fecit 1659.

L. Evans collection.

1658. Paper Quadrant in Collins's *Sector*.

1658. Paper Quadrant in Orrery Coll.

Paper prints of these quadrants were sold either loose or pasted upon boards by Henry Sutton, Mathematical Instrument maker, at his House in Thredneedle Street, behind the Exchange. 1659–60.

1661. Compass Card (revised, for use with Plane Table). (L.E.)

1669. 4⅜-in. Brass Quadrant in Orrery collection. No. 41.

Marked Hen: Sutton fecit 1669.

SAMUEL MORLAND.

1666. Adding Machine in silver. (L.E.)

EDWARD FAGE.

'At the Sugar Loaf in Hosier Lane London Fecit, who makes this [Scale] and all other Mathematecall Instruments.' (W. Leybourne, *The Art of Measuring*, 1669.)

PHILIP SIANRED.

Mathematician and Gauger in Bristol, 1667.

P. STAYNARD of Bristol.

Maker of Rules for Measuring.

PHILIP STANDRIDGE in Bristol.

Maker of Gauging Rods. (Sturmy, 1669, p. 25.)

ROBERT HOOKE (1635–1703).

Chorister or servitor of Christ Church, was the constructor of an Arithmetical machine in addition to his 'century of inventions'. An original Fellow of the Royal Society, who 'considered' all the scientific questions of his time.

JOHN BROWN.

1661. 'In Dukes place neere Aldgate.' (*The Description and Use of a Joynt Rule.* 168 pp. 12mo. 1661.)

1671. An almanack for ever. 'At Spheare and Sun Dial in the Minories.' (John Brown, *Horologiographia*, 1671.)

1671. The Triangular Quadrant 'made by John Browne at the Sphear & Sundiall in the Great Minories neere Aldgate London.' (J. Brown, *Description and Use of the Triangular-Quadrant*, with figure, 1671.) A part of the instrument in boxwood is in the Evans collection.

WALTER HAYES.

1672. Anderton's Quadrant or Panorganon.
'This Instrument or any other Mathematical Instrument is exactly made either in Silver,

Brass, or Wood by Mr. Walter Hayes at the Cross Daggers . . . at reasonable rates.' Engraving in W. Leybourn, *Panorganon or Universal Instrument*, 1672.

1674. Scala Agro-graphico-metrica.

An example of this rare instrument, mounted in an oak frame with a handle, is in the Evans collection. It was made by Hayes 'for J.W.', and is described by the inventor, J. Wybard, in *A Scalar Supplement*, in Leybourn's *Compleat Surveyor*, pp. 421–9, 3rd edit., 1674.

In Leybourn's 1673 edition of 'The works of that Famous Mathematician, Mr. Edmund Gunter, sometime Professor of Astronomy in Gresham College, London', a plate of a sector is given made by Walter Hayes, 'at the Cross-daggers in Moorfields,[1] next door to the Popes-head Tavern; where they make all sorts of Maps, Globes, Sea-plats, Carpenters Rules, Post and Pocket-Dials for any Latitude, &c.'

A similar advertisement appeared at the end of Samuel Sturmy's *Mathematical and Practical Arts*, 1676, p. 143, in which mention is made of several instruments all of which 'are accurately made by Walter Hayes'.

The Sector was also to be had from Anthony Thompson in Hosier Lane neare Smithfield.

Leybourn's *Compleat Surveyor*, 3rd edit., 1674, is illustrated with several engravings of scales by Hayes.

1679. Maker of The Scale of Scales. (Sturmy, *Mariner's Magazine*, 2nd edit., engraving facing p. 187.)

James Atkinson.

'All sorts of Mathematical Instruments in Wood or Brass, are Made and Sold by *James Atkinson*, at the *Cherry-Garden-Stairs* in *Redriff*.'

(Advertisement in J. Colson's Edition of Sturmy's *Mathematical and Practical Arts*, 1679.)

John Marke.

Silver Disk Protractor, 5-inch in diam. (L.E.)

1671. Dial at Drummond Castle marked 'Johannes Marke Londini fecit 1679'.

[1] Afterwards occupied by Edm. Culpeper, *c.* 1706.

BUTTERFIELD.

Instrument maker in Paris.

'Le sieur Butterfield Fabricateur des Instruments de Mathematique au Fauxbourg S. Germain, ruë neuve des Fosses aux Armes d'Angleterre, fait fort proprement le Cadran Cyclique, la regle de la Figure fondamentale et la Machine propre à poser les axes des Cadrans.'

An advertisement at the end of M. C.'s *Nouvelle methode pour apprendre à tracer facilement les Cadrans Solaires*. Paris, 1679.

1690. Dial.

ISAAC CARVER.

1667. Clockmaker (Britton).
1689. Slide Rule.
1697. } "At the Globe Dial, Horsley Down, Southwark,
1700. } London.'

ROBERT CHOULE.

'Mathematicall Instrument maker living at the signe of the Globe in ffleete-streete London', received as an apprentice John Coake, s. of J. Coake of Oxford, mercer, for 8 years from 7 August 1671.

[*Hannisters* $\left(\frac{L5}{4}\right)$ 1662-9.

WILLIAM BAKER.

Instrument maker of Oxford signed a bond before 6 Nov. 1680, when letters of administration of estate of Anne widow of William Potter, apothecary, were granted to Thomas Baker gent. (*Cur. Canc. Oxon. Wills*, &c.)

JOHN PRUJEAN.

Matriculated at Oxford on 11 March 1663. His name[1] appears as the vendor on the title-page of Richard Holland's *Explanation of Mr. Gunter's Quad-*

[1] John Prujean may have been related to Sir Francis Prujean, M.D., the celebrated physician of Caius College, Cambridge, who 'showed me his laboratory, his workhouse for turning, and other mechanics'. Pepys, *Diary*, 9 Aug. 1661. He died in 1661.

rant, as it is enlarged with an Analemma. Printed at Oxford 1676.

In 1689 'Mr. John Prijon and Mr. Henry Wyldgoose nue drawed and painted the Dial [of the church of St. Peter in the East] gratis'. (*Proc. Oxford Arch. and Hist. Soc.*, i. 298.)

'All Instruments for the Mathematicks are Made by John Prujean in Oxon.' (T.E., *Dialling Made Easy*, Oxford, 1692, p. 20.)

[T. Ellis was a Fellow of Jesus College.]

A Catalogue of Instruments *made and sold* by John Prujean *near* New College *in* Oxford. *With* Notes *of the* Use *of them.*

Holland's Universal Quadrant.
His Arithmetic Quadrant, serving to take Heights by inspection.
Oughtred's Quadrant.
Gunter's Quadrant.
His Nocturnal.
Mr. *Halton's* Universal Quadrant for all latitudes with Mr. Haley's notes.
Orontia's Sinical Universal Quadrant.
Mr. Caswell's Nocturnal.
Mr. Tomson's Pantametron.
Mr. Edward's Astrolobe.
Scales for Fortification.
His Double Horizontal Dial.
His Analemma.
Collins's Quadrant.
Napier's Rods.
Mr. *Haley's* Nocturnal.
Mr. *Pound's* Cylinder-Dial.
Mr. *Hooper's* Dialing Scales.
Scales for surveying, Dialing, &c.

And most other Mathematical Instruments.

(Advt. at the end of *Globe Notes* by R. Holland, Oxford, 1701. Bodl. Godwin Pamph. 1238.)

An 8-in. astrolabe by him signed 'Johã Prujean, fecit Oxon' printed from an engraved plate, and mounted on a circular oak base with an iron ring for suspension, is in the possession of Mr. L. Evans.

JOHN WORGAN.

Represented in the Oxford collections by three pieces. A Quadrant, a Surveying Compass, and a Plane Table. (1696.)

THOMAS TUTTELL.

1695. At the 'King's Arms & Globe, Charing Cross'.
1695. *Also* 'against the Royal Exchange in Cornhill'.
1695. 'Mathematical Instrument-maker at the King's Arms & Globe at Charing Cross.' (Tuttell, *Description and Use of a New Contriv'd*

ELIPTICAL / DOUBLE } *DIAL As also of the*
UNIVERSAL / AEQUINOCTIAL } *DIAL*, 1698.)

EDMUND CULPEPER.

1666. Sundial. (L.E. collection.)
Maker of a 12-inch Sector in brass and a 6¼-inch rectangular Protractor in silver. (L.E.)
1706. Succeeded Walter Hayes.
1710. Advertisement in Collins's *Quadrant*.

WILLIAM COLLIER.

Six-inch Sector marked 'W. Collier, Londini Fecit.' (L.E.)
1712. Brass Compass.
1730. Sector. (L.E.)

JOHN ROWLEY.

The work of this fine maker is probably better represented in the Orrery Collection of instruments at Christ Church than elsewhere. A number of the larger pieces were undoubtedly made to order, or with the certainty of their finding a place in the cabinet of his patron, but unfortunately none of them is dated. We have notes of dated work of Rowley, with his business addresses, as under:

1707. Fleet St. A Five-foot Rule with a sliding part; made for John Ward, *The Young Mathematician's Guide . . . with an Appendix on Practical Gauging*, p. 450.
1708. The Globe, under St. Dunstan's Church near Temple Bar, London.
1710. Johnson's Court, Fleet Street.
1716.

Another work by this maker was a sundial with an 'Aequation of Natural Days' and a remarkable list of places engraved upon it, erected in 1720 in Cranbury Park near Salisbury Plain. The tradition that it was set up by Sir Isaac Newton is given in Miss Yonge's 'Keble Land', and is reproduced in a recent number of the *Astronomical Journal* (1917).

Mr. G. H. Gabb informs me that he has in his collection a pocket Sundial engraved with the coat of arms of Lord Orrery and signed 'J. Rowley, Londini'.

An Analemmatic Dial by Rowley of the type described by T. Tuttell, *Description and Use of a New Contriv'd Dial*, 1698, see above, is in the Evans collection.

R. GLYNNE.

Maker of an upright case of Mathematical Instruments in silver with chased decorations, marked *R. Glynne fecit*, which resemble Rowley's work at Christ Church. On the top of the case is a representation of a crowned figure of Atlas carrying a Globe on his shoulders. (L.E.) See p. 47.

His date was *c.* 1705-55.

N. BION.

Ingenieur du Roi pour les Instrumens de Mathematique, Quay de l'Horloge du Palais, où l'on trouve tous ces Instrumens dans leur perfection. Author of the *Traité de la Construction et des principaux usages des instruments de Mathematique.* 1709.

THOMAS HEATH.

c. 1714. Made a Calendar.

1729. Thos. Heath *at the Hercules and Globe next the Fountain Tavern in the Strand Makes and Sells Wholesale and Retale all sorts of Mathematical Instruments in Gold, Silver, Brass, Ivory, or Wood with Books of their Use.*

Plate in S. Cunn's *New Treatise of the Construction and use of the Sector,* revised by Edm. Stone, 1729.

Oval, upright Case of Instruments 5½ inches high. (L.E.) See p. 48.

1747. Opposite Exeter Exchange, Strand.
1757.
1768–74. Heath and Wing appear in Kent's *Directories* as 'Mathematical Instrument Makers, Strand'. Their name does not appear in 1776. They are the makers of the Orrery in All Souls College.

GEORGE GRAHAM (1675–1751), F.R.S., 1720.

Mechanician: succeeded Tompion as watchmaker, and is buried with him in Westminster Abbey. He lived at No. 67 Fleet Street (corner of Whitefriars St.), with Tompion until 1720, when he removed to the Dial and One Crown, opposite the Bolt and Tu , Fleet St. The quaint little shop had two plain bowed windows, with the doorway between them. He was succeeded by Mudge and Dutton. The house was (1850) one of the last in Fleet St. to be modernized. It is No. 148, and now the offices of the *Sporting Life*. (Britten, *Clockmakers*.)

'Manual dexterity remarkable, and his precision of construction and thoroughness of work unrivalled.' Designer of the 8-ft. Mural Quadrant at Greenwich.

WILLIAM PARSONS.

Protractor and Scales in brass, marked 'W^m^ Parsons Fecit'. (L.E.)

WILLIAM DEANE.

1720. A large Compass Dial. (L.E.)
n. d. Large Universal Dial, marked 'W^m^ Deane Fecit in Crane Court, Fleet St. London'. (L.E.)
? 1740. 4½-inch Sector 'W. Deane Fecit'. (L E.)

DOLLOND.

6-inch Sector in silver 'Dollond, London'. (L.E.)
Rolling Parallel Ruler. Inv^t^. by A. G. Eckhardt, made by P. and S. Dollond in St. Paul's Churchyard, London. (L.E.)

JONATHAN SISSON (1690?–1760?).

'I think it proper to say, that I have seen a *Theodolite* made by Sisson, *Mathematical Instrument Maker*, at the Corner of *Beaufort-Buildings* in the *Strand*, for

Accuracy and Dispatch, fitter for a Surveyor than any other I have yet seen.' (S. Cunn, *An Appendix . . . relating to . . . Land-Surveying*, p. 143, with Leybourn's *Compleat Surveyor*, 1722.)

'In the Strand Mathematical Instrument Maker to His Royal Highness the Prince of Wales.' (Wm. Webster, *Course of Pract. Mathematicks*, 1730.)

5-inch Protractor, beautifully decorated, in a shagreen case. (L.E.) Marked S
I ∗ S.

1735. Sundial. (L.E.)

1739. An engraving executed by Sisson appears as a frontispiece to W. Webster, *Description and Use of a Complete Sett or Case of Pocket Instruments*, 2nd edit., 1739. In the 1768 edition of the book the frontispiece was printed again from the same plate, after Sisson's name had been removed, although his beautifully executed ornament was retained.

In 1739 he was living 'at the corner of Beaufort Bdgs., Strand'. In 1740 he sent a transit instrument of 5 ft. focus to Leyden.

Samuel Cunn, whom we have mentioned twice, was 'A Butcher that kept a Butcher's Shop in Newport Market', also a very great Mathematician: one of the best measurers of artificers' Works, Surveyers of Land, and Expounders of Euclid and Apollonius in the World; the real writer of part of Hammond's *Surveying*. (Stone, *Suppl. to Bion*, p. 302.)

BENJAMIN SCOTT.

c. 1733. In the Strand.

'Makes and Sells all Sorts of Mathematical Instruments in Silver, Brass, Ivory, and Wood . . . all Sorts of Sliding Rules, Parallel-Rules, best Black-lead Pencils.'

A Brass rule with sights in the possession of Mr. Lewis Evans is marked B. Scott *fecit*.

In 1733 he published *The Description and use of an Universal and Perpetual Mathematical Instrument*, London, 1733. It was a circular Slide Rule, over 18 in. in diameter, and consisted of 20 circles.

This work includes a Table of the Cycle of the Sun in an engraved border executed by Scott.

JOHN COGGS and WILLIAM WYETH.

'Ingenious mathematical instrument makers near St. Dunstan's Church in Fleetstreet', who made a rule with Shirtcliffe's SR line. (*Theory and Practice of Gauging*, 1740.)

GEORGE ADAMS, instrument maker to George III.

Designed a Spiral Ruler in 1748. It was engraved on a brass plate 12 in. in diameter and had ten spiral turns. (*Nicholson's Journal*, i, p. 375, 1797.)

Issued a Catalogue of instruments made and sold by George Adams, maker to his Majesty, and optician to H.R.H. the Prince of Wales. No. 60 Fleet St. London, 1787. (L.E.)

JOHN BIRD (1709-76).

Came to London in 1740: engaged by Sisson to divide instruments. Graham instructed him, and in 1745 he opened a business in the Strand: in 1748 he began to refit Greenwich Observatory, and in 1749-50 he made the 8-ft. Quadrant at a cost of £300. (*D.N.B.*)

JESSE RAMSDEN (*b.* 1735, *d.* 1800).

Married Dollond's daughter.

The telescopic part of a Transit Instrument labelled 'J. Ramsden, made for A. Cumming, 1772, London', is in the Guildhall Museum.

JOSEPH JACKSON of London.

1740-50. A Universal Ring Dial (L. Evans collection). A magnificent instrument with a Vernier Scale reading each way. Perhaps the earliest instance of the application of the Vernier to a Ring Dial.

JOHN WARNER of London.

An improver of the Slide Rule who added 'a curious scheme of both sides of the Rule, and of the Scale'.[1]

'These rules & all other Instruments for Mathematicall practice are made & sold by John Warner

[1] Coggeshall, *Art of Practical Measuring*, 1722 edit.

at ye King's Armes & Globe in little Lincoln's Inn Fields at ye end of Portugall Row, London.'—By H. C. Gent (= Henry Coggeshall).

THOMAS WRIGHT.

1718. 'Int Maker to the Prince of Wales', 'Fleet Street'.
1722. 'Mathematical instrument maker to his Royal Highness, the Prince of Wales', sold slide rules in Fleet St. (*Coggeshall*, 1722.)
1731. Sept. 17. Took an inventory of the Mathematical Instruments in the library of the Rt. Hon. the Earl of Orrery, deceased, which are now at Christ Church. The inventory is addressed to the 'Revd. John Fanshawe at Christ Church College, Oxon.'
1733. Int Maker to George II at the Orrery and Globe.
1751. Succeeded by B. Cole.

B. COLE.

1751. Continued the business of Th. Wright in Fleet Street, London.

EDW. TROUGHTON (1753-1835).

Admitted to partnership with his uncle of same name and his eldest brother John, who were settled in London as mathematical instrument makers. His work was in the greatest repute after the death of Ramsden.

In 1782 the Troughtons set up at 'Ye Orrery' as successors to *Wright* and *Cole*.

Edw. Troughton (the uncle) and John T. (brother) died leaving Edw. Troughton alone until 1826, when he took WILLIAM SIMMS (1793-1860) into partnership.

In 1831 Edw. Troughton retired, and in 1860 William Simms died, and was succeeded by his son James Simms, the present sole proprietor.

JAMES SIMMS, bro. to Wm., was a manufacturer of ships' and other compasses in Greville Street, Hatton Garden. His son William S. (1817–1907), F.R.A.S., was for a time superintendent of the business, but he

retired in 1871. As a hand-divider of instruments 'he could scarcely be excelled'.

E. SCARLET.

1753. Diagonal Bars with Royal Society scale for thermometers marked *E. Scarlet Fecit.* (L. Evans collection.)

BENJAMIN PARKER.

1753. A special Slide Rule containing a telescope with two separate sliders at its sides. 12 in. × $1\frac{13}{16}$ in. × $\frac{7}{8}$ in.

Marked: 'Io^s. Saxspeach Inv^t. Ratcliff Ianuary 1753. Ben. Parker Fecit'. (L.E.)

E[DWARD] NAIRNE. 20 Cornhill, London.

c. 1778. Nairne and Blunt of Cornhill made Robertson's improved Sliding Gunters in which a runner was used for the first time.

1793. Hall-mark on silver and shagreen drawing instruments. (L.E.)

THOMAS JONES, London (1775–1852).

Of Holborn. He made Henderson's Double 12-in. Slide Rule. Also an instrument marked 'Tho. Jones Patent, No. 38', on the principle of the 'lazy tongs', for subdividing a short line into any number of equal parts up to eight in number. (L.E.)

Proportional Compasses. 'Thos. Jones, 62 Charing Cross, Lond.' (L.E.)

CARY of the Strand made Bevan's 12-in. Engineer's Rule.

ROOKER of Little Queen Street, London.

1815. Maker of Roget's Sliding Rule. (*Phil. Trans.*, 1815.)

c. 1830. Maker of Woolgar's Pocket Calculator.

EARLY SCIENCE IN OXFORD

Part I, Chemistry, was printed for the author in October 1920 for sale at the Oxford Science Laboratories at the cost price of six shillings. On publication it was found necessary to raise the price to ten shillings and sixpence.

The printing of Part III, Astronomy (the manuscript of which is ready), is held up by the present high cost of the many illustrations that will be necessary to do justice to the great wealth of valuable and hitherto undescribed astronomical instruments that are in Oxford.

Offers of subscription to a guarantee fund to cover the cost of the plates will be gladly received by the author, R. T. Gunther, Magdalen College, Oxford.

PRINTED IN ENGLAND
AT THE OXFORD UNIVERSITY PRESS
BY FREDERICK HALL

DR. ROBERT RECORDE OF ALL SOULS COLLEGE, 1556

From the only known portrait of the 'Father of British Mathematics', now in the possession of Mrs. Done Bushell and lent by her for exhibition in Oxford in 1923 with the L. Evans Collection of Scientific Instruments

O

EARLY SCIENCE IN OXFORD

PARTS III & IV
PHYSICS AND SURVEYING

BY

R. T. GUNTHER
MAGDALEN COLLEGE, OXFORD

PRINTED FOR THE AUTHOR
AT THE OXFORD UNIVERSITY PRESS
1923

PRINTED IN ENGLAND
AT THE OXFORD UNIVERSITY PRESS
BY FREDERICK HALL

INTRODUCTORY

Of the early inventions of first-rate importance of the fourteenth century the Horologe of Richard of Wallingford is only represented by a picture, but of Trigonometrical Methods of Surveying and of the Weather Journal of Merle we have original MSS. all by members of the Merton School. Of the work of the great Oxford inventors of the seventeenth and eighteenth centuries, of the air-pump, of the first microscope, balance spring and anchor escapement of time-pieces, barometer, hygrometer, of the magnetic inventions of Gowin Knight, or of the first electric battery, neither in Oxford nor out of it, are there any examples to show. We can but recall the great names of those whose posthumous honours have not brought about the preservation of the instruments for which they are famous in their own country. Roger Bacon, Hariot of St. Mary's Hall, Recorde of All Souls, Fludd of St. John's and Christ Church, Digges of University College, Cartwright of Magdalen, all appear on the roll of remembrance. Notwithstanding that Wren, Hooke, and Boyle seem to have had a hand in every scientific invention of their age, no scrap of their work is now extant. Is not this neglect the strongest of all arguments for the need of a *Museum for Scientific Instruments*?

Of instruments of especial value that have survived are the Marshall Microscope, Worgan's Plane-Table, Rowley's Bubble Levels, the Thermometers of Six and Bréguet, all among the earliest of their kind in the world.

For the frontispiece to this part we gratefully acknowledge the loan of the unique portrait of Robert Recorde by Mrs. Done Bushell of Harrow, a photograph of which we are thereby able to publish for the first time in his own country. Several blocks have been lent by the Royal Geographical Society; and to all the Colleges and University Institutions our thanks are again due for much sympathetic help in various ways.

Instruments in Oxford collections are distinguished by serial numbers.

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THE TEACHING OF NATURAL PHILOSOPHY IN THE EIGHTEENTH CENTURY

IN beginning this account of early Physical instruments and studies in Oxford by a chapter, dealing with the teaching of Natural Philosophy in the eighteenth century, taken away from its chronological sequence, we desire to emphasize an advance of signal importance in the method of teaching Natural Science, namely, by the adoption of the experimental lecture.

It will be remembered that one of the guiding principles which regulated proceedings at the meetings of the Royal Society during the preceding century was that discoveries communicated to the Society should be proved by experiments before a Committee. Notes of what was observed were taken, and these were afterwards entered in the register book. As Dr. Sprat put it, 'The work which the Society proposes to itself is not so fine and easie as that of teaching is, but rather a painful digging and toiling in nature.'

It was this 'digging and toiling' in the presence of an audience that, carried into teaching, distinguished the best Lectures on Natural Philosophy of the eighteenth century from the dogmatism of previous systems.

The high appreciation of the beauty and interest of scientific instruments in the seventeenth and eighteenth centuries is well illustrated by the frontispiece to a sumptuously printed folio, *Recueil de plusieurs Traitez de Mathematique de l'Academie Royale des Sciences*, Paris 1676, where the *Grand Monarque* and various members of his court are being shown philosophical instruments and anatomical preparations apparently to their great contentment. Scientific studies were eminently fashionable.

At the beginning of the eighteenth century Natural Philosophy was being taught by College Lecturers at certain of the Colleges, e.g. Magdalen and Brasenose, and the existence of a reputable maker or vendor of philosophical instruments in Oxford was a useful adjunct, and may be taken as some indication of a certain demand. This was JOHN PRUJEAN, who lived near New College and advertised his wares at the end of books (see p. 180).

DR. GREGORY, the Savilian Professor of Astronomy, proposed a scheme for regular systematic teaching of the subject, which was submitted to Pepys in October 1700 for perusal and criticism. It is printed among the Pepysian Correspondence.

DR. GREGORY'S SCHEME

Without discouraging any other person in the University, that teaches or intends to teach mathematics, Dr. Gregory undertakes to teach the different parts and sciences of mathematics by Colleges or Courses, after the manner following:—

If any number of scholars desire him to explain to them the Elements, or any other of the mathematical sciences, if they are already acquainted with the elements, he will allow that company such a time as they among themselves shall agree upon not less than an hour a day for three days in the week; in which time he will go through the said science, explaining every proposition and illustrating it with such examples, operations, experiments, and observations as the manner shall require, until all the company fully apprehend and understand it.

And because some may be desirous to give an account of their proficiency for their own satisfaction and that of their friends, he will once a week examine such as shall signify that they are willing to be examined.

The courses or colleges of most ordinary use are these:

1. The first six books with the eleventh and twelfth of Euclid.
2. The plain trigonometry.
3. Algebra.
4. Mechanicks.
5. Catoptricks and Dioptrics. Where the effects of Mirrors and Glasses are shown; the manner of vision

explained; and the machines for the helping and enlarging the sight (as telescopes, microscopes, etc.) described.

6. The principles of Astronomy.

7. The theory of the Planets.

Any one of these Colleges was estimated to require about three months; and the number of scholars proper for such a class is more than 10, and not more than 15.

It is uncertain whether Dr. Gregory actually placed himself at the disposal of companies of scholars clamouring for examples, operations, experiments, observations, and examination once a week, but as likely as not he contented himself with 'very readily', *more professoris*, giving advice concerning their studies. We do know that his favourite Edinburgh pupil, JOHN KEILL[1] (1671–1721), followed him to Oxford, entered at Balliol in 1694, and exhibited experiments illustrative of the Newtonian Philosophy by means of an apparatus of his own invention. In 1700 Keill lectured on Natural Philosophy as deputy for the Sedleian Professor, Sir T. Millington, and published his *Introductio ad veram Physicam* in the next year.

Among those who attended his course at Hart Hall in November 1701 was the grandson of John Evelyn, a serious youth, who wrote to his grandfather in Latin to say that after studies *de motu et mixta Mathesi*, he was attending the public lectures of Keill on Gnomics and Hydrostatics on alternate days. Many Christ Church men were also attending the course. (Pepys, *Correspondence*.)

There is an appreciation of Keill's work in Oxford, before he left for his American trip, in the preface to *A Course of Experimental Philosophy*, written by his successor. 'Whereas', writes Desaguliers, 'the great Mr. Locke was the first who became a Newtonian Philosopher without the help of Geometry, and as Sir Isaac Newton himself said, read the Opticks with pleasure, acquainting himself with everything in them that was not merely mathematical, Dr. John Keill was the first who publickly taught Natural Philosophy by experiments in a mathematical manner; for he laid down very simple Propositions, which he proved by Experi-

[1] Elder brother to James Keill, the Anatomist.

ments, and from those he deduc'd others more compound, which he still confirmed by Experiments; till he had instructed his auditors in the *Laws of Motion*, the *Principles of Hydrostaticks* and *Opticks*, and some of the chief Propositions of Sir Isaac Newton concerning *Light* and *Colours*. He began these Courses in Oxford about the year 1704 or 1705[1] and that way introduced the Love of the Newtonian Philosophy.'

In 1710 JOHN THEOPHILUS DESAGULIERS (1683-1749) was reading lectures on Experimental Philosophy at Hart Hall in succession to Keill, who was appointed Savilian Professor of Astronomy[2] after Caswell in 1713, the year Desaguliers removed to London.[3] He seems to have spread the Newtonian Philosophy among 'persons of all ranks and Professions, and even among the Ladies, by the help of Experiments, being an indefatigable lecturer'. Writing in 1745 he notes that the course he was then engaged in, was the 121st since he began in Oxford in 1710. He added Mechanics and several Optical Propositions to Keill's course and endeavoured to make his discourses understandable to auditors but little versed

[1] This date is probably late by four or five years.

[2] One of the Savilian Professor's later lectures was printed under the title of:

J. Keill, M.D. *An Introduction to the true Astronomy.* Read in the Astronomy School of the University of Oxford. 2nd edition, London, 1730.

He also wrote *An examination of Dr. Burnet*, dedicated to Dr. Mander. 2nd edition, 1734.

[3] This experimental course of Desaguliers is said to have been the first given in London, but William Whiston seems to have started lecturing at the same time, while FRANCIS HAWKSBEE made the experiments.

Desaguliers lectured at Channel Row, Westminster, on a syllabus, printed (n.d. *circ.* 1714) in English and French, entitled *Course of Mechanical and Experimental Philosophy*, for a fee of £3 3*s*. One of his auditors, Paul Dawson, appears to have taken notes which he published in 1719 under the title of *A System of Experimental Philosophy Prov'd by Mechanicks*, 201 pp., 'by Desaguliers', who repudiated the version and no doubt caused the Bodleian copy to be marked 'This is a spurious copy publish'd without ye consent of the Author'.

According to Horne, afterwards President of Magdalen, one of those who attended the lectures was the philosophical instrument maker Ben Martin, 'who having attended Dr. Desaguliers' fine raree, gallanty show for some years in the capacity of a turnspit, has, it seems, taken it into his head to set up for a philosopher'.

in Mathematics. 'I only require Attention and Common Sense, with very little Arithmetic.' He hoped 'the rigid Philosophers' would forgive geometrical demonstrations in the annotations. Such were the aspirations of the lecturer, but an external criticism was that the lectures became more mathematical and less experimental as time went on. Nevertheless, a lecturer cannot be regarded as unsuccessful who had his king among his audience and who had delivered 121 courses between 1710 and 1745. With Dr. S. Hales he invented and exhibited an engine for sea-soundings in 1728.

In the Bodleian Library are three volumes of Lecture Notes on Mechanics, Hydrostatics, and Pneumatics[1] which were written early in the century. The following paragraph will give some idea of the lecturer's style, who in another passage mentions 'Our excellent Mr. Boyle' and his air-pump (pp. 139-40).

'It may not be amiss to add in this place the Result of a Computation which I made of the weight of all the Air, which presses upon the Surface of the Earth. If this weight were to be express'd by the number of Pounds it contains, that number would be so large as in a manner to be incomprehensible. I will then make use of another way of expressing it by determining the ½ diameter of a sphere of Lead of the same weight with all the Air which presses upon the surface of the Earth. Now that ½ diameter was found to be very nearly 30 miles long.'

During the first quarter of the eighteenth century some helpful demonstrations in experimental philosophy were given by J. WHITESIDE, Keeper of the Ashmolean.

'Our industrious and faithfull Keeper of our Musaeum Mr. Whiteside, is going to London to visit the Virtuosos, being also a Fellow of the R.S., and to take advice and Instructions particularly from our good freind Dr. Sloane, being not more willing to ask Councill, than to follow it.

'He has had lately a Collegium-Mathematicum of a months course, where he taught the youth of several Colleges, particularly the young most hopefull studious Duke of Queensbery, Marquisse of Hartinton, etc. He goes thro all the parts of Natural Philosophie Experi-

[1] Sum. Cat. 29566.

ments and Mathematics, for which he is very well accomplished, with excellent Instruments well made, at expense of neare 300*l*. His price is a giny and a half, I wish every gentleman and student of the University were enabled by theyr freinds, if they have any genius, to go thro a whole course. Those two young noblemen have been very diligent, attentive and much pleased, w[h] the Operations and Lectures.'[1]

That he was lecturing on chemistry in 1720 is shown by the notes of the course in MS. Ashmole 1820[a], f. 302. Hearne knew him well, and while noting his death on 22 Oct. 1729, added:

'He was a very ingenious industrious man, an excellent mathematician, and one of the best in England in experimental philosophy. He carried on a course of experiments for many years at the Museum, to the great advantage of the youth of the University.' This 'he did for himself, and not as *custos musei*, and might therefore have done it elsewhere as well, if he had provided himself of a room. . . .' The diarist also records that there was a valuable collection of apparatus. 'Mr. Whiteside said last Night that he values his Glasses and other Mathematical Instruments, w[ch] he keeps at the Ashm. Museum, at four hundred pounds' (Hearne, Nov. 15, 1723). On occasion, as on 30 Jan. 1724/5, he went up to London on business 'relating to his experiments'.

There does not appear to have been any one to deliver regular courses of experimental lectures for some few years, but that there was a need of them is shown by a letter in the Bodleian, quoted by Rigaud, in which Dr. John Richardson speaks with approbation of Mr. Whiteside's 'designe of experimental philosophick lectures'.

Whiteside was a chaplain of Christ Church and Keeper of the Ashmolean Museum, where he lectured. Having divided the entrance hall into two, it is said that when he finished the delivery of his lecture in one, the class removed into the other where a servant exhibited to them the experiments which illustrated the subject on which they had been engaged. (Rigaud.) Dr. Richardson's letter was dated 11 June, 1716, so it may be that

[1] Letter of A. Charlett to Richardson, dated Ladyday 1716.

the experimental lectures were renewed about this time, and were continued until 1728. A series of thirteen notes on Whiteside's lectures on Optics is in the Bodleian, MS. Bradley 48.

By 24 Jan. 1729 he sold his apparatus, 'the best that is known, for more than £400 to Mr. Bradley', it was reported by Hearne, but on 13 Feb. 1730 he corrects the price according to later information; he was informed that Bradley 'gave only £170, tho' I had been before told, that he gave four hundred lib^s for them. Mr. Whiteside, several years agoe valued them at £500, and at last at £800.'

In 1729 BRADLEY commenced to give the experimental lectures, and was accommodated with the rooms in the Ashmolean when he purchased the apparatus. Rigaud mentions a register of those who attended these lectures between April 1746 (when he began his forty-seventh course) and April 1760, when he read for the seventy-ninth and probably last time. From these accounts it appears that till the end of 1749 he was in the habit of lecturing three times a year; between Christmas and Easter, between Easter and the Long Vacation, and again in Michaelmas Term. After 1749 he did not repeat his course in the autumn; probably because he was engaged in new duties at Greenwich, and could less afford to be absent from his astronomical studies there. The thirty-three classes, of which we have the particulars, average fifty-seven attendants at each; and as he received two guineas from every pupil for the first, and one guinea for the second attendance, his annual receipt must have been something considerable: this afterwards received a small increase. In 1731 £30 of Lord Crewe's benefaction was set apart by Convocation for a 'reader of experimental philosophy', but it was only on the extinction of the life interest of Lady Stawell that Bradley received any increase of salary.

'Among the old apparatus belonging to the lectures of experimental philosophy at Oxford there was a small machine to illustrate the doctrine of aberration. Bradley never wrote out his lectures, and in the notes from which he delivered them, no notice of it can be discovered; but still there is every reason to believe that it was his own contrivance. It consists of a box, the

lid of which is made to slide laterally by a screw which is under it, and to the axis of the screw the two extremities of a silken thread are attached. By this construction one end is wound up on the cylinder while the other is unwound, and a mark on the thread representing a particle of light is thus made to move at right angles to the direction in which the lid is carried. The mark passes over the diagonal of a parallelogram, the sides of which represent the two motions, and shews the apparent direction in which the light would enter the eye.' (Rigaud.)

In 1731 he was beaten in his candidature for the Keepership of the Ashmolean by Joseph Andrews of Magdalen. Next year he came to reside at Oxford in the professor's house in New College Lane.

The Origin of the Laboratory for Experimental Philosophy

No historical account of the progress of Experimental Philosophy in Oxford should omit to mention that in 1753 died Henry Hyde, great-grandson of the great Earl of Clarendon. By his will the Chancellor's MSS. were bequeathed to the University of Oxford, to be printed at their press, and the profits to be devoted to a **School for Riding** and other athletic exercises in the University, should such an institution be accepted, or else to other approved uses.

More than a century later, on Feb. 4, 1868, it was decided that members of the University did not need a Riding School but that the accumulated fund (now amounting to about £12,000) might be applied to the erection of laboratories, &c., at the University Museum, for the Professor of Experimental Philosophy. (Macray, *Annals of Bodleian Library*.)

Lectures on Experimental Philosophy

Concerning Dr. Thomas Hornsby, Reader in Experimental Philosophy (1763-1810), opinions are somewhat divergent, but they may refer to different periods in his career.

Dr. Hornsby received an honorarium from the several members of his class, and was known to be an able

and scientific man. His mode of instruction was peculiarly clear, his language correct, with choice phrases and well-turned periods; with something too much of precision, and, if the word may be permitted, of pedantry.

Best, who attended his instruction, recalls an occasion when the Reader, to show some experiments of the air-pump, procured a cat, which he placed under the receiver: on beginning to draw away the air, he would say, 'You will observe, gentlemen, that the animal exhibits symptoms of uneasiness': after two or three more pulls, 'The animal seems to be considerably incommoded'; and such was his forgetfulness of the consequences, while contemplating the wonderful effect of the subtraction of vital air, that, but for the admonition of his servant, who declared that Mrs. —— would never forgive him if he did not bring back her cat safe and sound, the cat would have been in the *cat*egory of the loss of nine lives.

'The professor loved a joke. . . . When any of his pupils crossed the room in such a manner as to intercept the rays of light in their way to the spectrum, he would say, "Sir, the head is an opaque body." And he generally met with a head of sufficient opacity, as well as incapable of *reflection*.'

He was subject to epileptic fits: the symptoms of their access were well known to his servant, who, placing an arm-chair behind him, laid him gently in it, and administered the usual helps. When the fit was over, the lecture was resumed by the professor, precisely at the point at which it had been interrupted; in the midst, it might be, of some abstruse or subtle explication.

Dr. Hornsby was a man of whom all his friends spoke with affection, and all strangers with respect.[1]

On the other hand Dr. T. Hornsby of C. C. C., Savilian Professor of Astronomy, and A. Robertson, Savilian Professor of Geometry, were among those Oxford Professors of whom Adam Smith in 1776 had asserted 'the greater part . . . have for these many years given up altogether, even the pretence of teaching'.

Three years later, in Nov. 1779, James mentions him as 'reading a course of lectures. His terms were 2

[1] Best, *Personal and Literary Memorials*.

guineas the first course, one the second, and for ever after gratis.'

On May 23, 1781, lectures were given in Experimental Philosophy probably by Hornsby, and in Botany by a Mr. Shaw.[1]

A fruitless attempt to establish an evening school for young mechanics was made about 1780 by Dr. ABRAM ROBERTSON, but he soon found that 'they spend their money and their evening-hours otherwise than their likes do in Scotland'.[2]

In an age where originality was so rare, it is a relief to come across the record of the apothecary to the Radcliffe Infirmary, one RICHARD WALKER (1828), who made a series of experiments on the production of Artificial Cold. His demonstrations were witnessed by several eminent members of the University and later by Dr. Beddoes' class.

1786,	28 April.	47° and 22° of Cold produced.
1787,	21 March.	Dr. Beddoes repeated the experiment.
	20 April.	84° of cold produced: quicksilver frozen.
1788,	30 Dec.	
1789,	10 Jan.	Quicksilver frozen in presence of Dr. Bourne.
	12 Jan.	Quicksilver frozen in Anatomy School, Christ Church, in the presence of Hon. Wenman, Rev. Dr. Hoare, Dr. Sibthorpe, jun., Rev. Mr. Jackson, Ch. Ch., Mr. Wood of the Radcliffe.
	14 Jan.	" " in the presence of the Dean of Christ Church, Rev. Dr. Hornsby.
	12 March.	In Laboratory before Dr. Beddoes' class.

THE TEACHING OF NATURAL PHILOSOPHY IN THE EARLY NINETEENTH CENTURY

During the first two decades of the nineteenth century 'Ashmole's ample dome' must have often proved too cramped a cover for the adequate setting forth of all the

[1] GEORGE SHAW of Magdalen Hall, 1765-9, M.B. and M.D. 1787, was the 'cockle-shell' brother of Dr. Shaw of Magdalen. (Cox, *Recollections*, p. 111.)

[2] Cox, *l. c.*, p. 145.

Sciences, the Professors must often have been tumbling over one another in their struggles for class room. And so, when the University Press left its old and narrow quarters in the Clarendon Building, the Professors of Natural Philosophy and Geology were not slow to apply for the spacious apartments on the first floor of that building. The two eastern rooms were allocated to Natural Philosophy and were refitted according to a scheme of Professor Rigaud, assisted by the architect Smirke. The cost of this, the Clarendon Laboratory No. 1, was defrayed out of a grant of £3,000. The SE. room was furnished for lectures on Natural and Experimental Philosophy with accommodation for seventy students; there were cases for apparatus against the walls and on the north side was a model of a steam engine. The NE. room is marked 'for lectures not requiring any fixed apparatus', on a plan now in the Archives.

'A short time after the publication of Faraday's first researches in magneto electricity, he attended the meeting of the British Association at Oxford in 1832. On this occasion he was requested by some of the authorities to repeat the celebrated experiment of eliciting a spark from a magnet, employing for this purpose the large natural magnet in the Ashmolean Museum. To this he consented, and a large party assembled to witness the experiments, which, I need not say, were perfectly successful.

'Whilst he was repeating them, a dignitary of the University entered the room, and addressing himself to Professor Daniell, who was standing near Faraday, inquired what was going on. The Professor explained to him as popularly as possible the striking result of Faraday's great discovery. The Dean listened with attention and looked earnestly at the brilliant spark, but a moment after he assumed a serious countenance and shook his head;

'"I am sorry for it", said he, as he walked away; in the middle of the room he stopped for a moment and repeated, "I am sorry for it"; then walking towards the door, when the handle was in his hand he turned round and said, "*Indeed* I am sorry for it; it is putting new arms into the hands of the incendiary."'

'This occurred a short time after the papers had been filled with the doings of the hayrick burners. An erroneous statement of what fell from the Dean's mouth was printed at the time in one of the Oxford papers. He is there wrongly stated to have said, "It is putting new arms into the hands of the infidel".'[1]

On 11 June, 1849, Baden Powell asked for rooms under the Ashmolean Museum. He lectured on many subjects. One lecture was 'On certain Phenomena of Rotatory Motion', which he illustrated by an appliance of his own construction, to exhibit experimentally the actual composition of rotations about two different axes impressed at once on the same body.[2]

[1] Tyndall, *Faraday as a Discoverer*, p. 32.

[2] *Lecture to Royal Institution*, March 1854. Cf. *Ashm. Soc. Notices*, xiii, p. 221.

MECHANICS

Although the Mechanics of rigid bodies is no doubt rightly to be regarded as the oldest of the several branches of applied science, yet it is only in quite recent times that noteworthy advances have been made on the knowledge left by the Greeks. Indeed it is surprising how ignorant the world remained of the most elementary mechanical principles until the early years of the seventeenth century. About 1575, so little was known of Dynamics, that it was still asserted[1] on the authority of Aristotle that the rate at which bodies fell, varied directly as their weights. In Statics the question of the resultant of forces, acting on a particle, was still an unknown branch of the subject, though the special case of two forces at right angles to each other acting on a particle was known.

The first impulse to a more modern conception of the science of Mechanics came from Simon Stevinus of Bruges (1548–1620), who died at the Hague. In 1586 Stevinus treated the triangle of forces as the fundamental theorem of Statics—a method which was adopted by Galileo (1564–1642), the father of the science of Dynamics, and a great example of the scientific discoverer whose success depends chiefly upon having a mind sufficiently practical to make the best use of those instruments which chance has thrown before his eyes.

At Pisa the leaning tower afforded an almost unique facility of testing Aristotle's assertion about falling bodies. Numberless people must have taken a childish pleasure in dropping stones, &c., from the overhanging parapets on to the ground below, but no one before Galileo had studied and correctly stated the law of their falling. By means of experiments on the large scale that was possible owing to the height of the tower, Galileo soon found that, except for a certain retardation due to the resistance of the air, all heavy bodies fell at the same rate and through distances proportional to the square of the time which had elapsed since the beginning of their falling. Nor in all probability would he have made this great discovery, had he not become Professor of Mathe-

[1] Ball. *Mathematical Science in the seventeenth century. Camb. Mod. Hist.* v.

matics in his native City of the Leaning Tower. It was a great opportunity: the apparatus for his experiment was ready, and he used it. His merit was the greater, because unlike so many of his contemporaries he placed greater reliance in the truth of his demonstration than in the hitherto unshaken authority of Aristotle. His scathing criticism of the arguments of those who nevertheless tried to re-establish the worthless statement of the Greek philosopher, was in a personal sense unfortunate, for he made enemies, who in 1591 obliged him to resign his chair.

But he had already studied the path of a projectile, and had proved it to be a parabola. He was almost certainly familiar with the principles of Newton's first two Laws of Motion, and from noticing the swinging of a great bronze lamp hanging from the roof of the cathedral had deduced the law that pendulums of the same length are isochronous, or perform their swingings, whether long or short, in equal times. The results of his experiments with pendulums were explained in a most lucid manner in his work on Mechanics published in 1638, and just before his death he turned them to practical use by the invention of a pendulum clock.

Galileo's experiments on the swing of pendulums were continued by HUYGENS (1629-95), who arrived at conclusions concerning the motion of bodies of finite size and at a determination of the centrifugal force on a body moving in a circle with uniform velocity.[1]

In England THOMAS HARIOT of Oxford *c.* 1604 had also been investigating the time that various bodies took to fall 43 feet, the fall of water 'ad Croyden River', the flow of water in pipes, and he noted that 'bodies moving in a medium do affect to carry a pyramid of the same medium [in front of them] but the top is broken off'. MS. Addit. 6788, f. 145.

The Hon. ROBERT DUDLEY of Christ Church, 1587 (afterwards created Duke of Northumberland in the Holy Roman Empire), 'contrived many Engines and Mathematical Instruments not known before and now in the possession of the Great Duke of Tuscany, to whose ancestors he applied himself in his discontent, by whom he was succor'd and highly valued for his

[1] Huygens, *Horologium oscillatorium*, Paris, 1673.

great learning, and with whom his children now remain to this day in wealth and honor, retaining the titles of Dukes of Northumberland, &c.'[1]

Dudley seems to have been a universal mechanical genius. In 1614 he wrote a letter from Leghorn describing his nautical inventions. Cosmo II of Tuscany was very greatly impressed by his ingenuity as a ship-builder and mathematician, and his son Ferdinand II, who succeeded to the Duchy in 1621, employed Dudley to drain the morass between Pisa and Leghorn, 'an operation to which the town of Leghorn owed its future prosperity' (*D. N. B.*). Shortly before his death he published the magnificent work by which he is best known, *Dell' Arcano del Mare*, Florence, 1646-7, dedicated to Ferdinand II, Duke of Tuscany. Of the six books, the first deals with longitude and the means of determining it; the second supplies general maps, charts of ports and harbours, in rectified latitude and longitude; the third treats of maritime and military discipline; the fourth of naval architecture; the fifth of scientific or spiral navigation; and the sixth is a collection of geographical maps.

Great progress was made in the mechanical arrangements for improving the navigation of the upper Thames about 1624. It was in this year that three 'Turnpikes' were constructed, one at Iffley, another at Sandford, and the third at Culham in the Swiftditch, by which the river was made navigable from Oxford to Burcot.

A Turnpike was what we now call a Lock; it consisted of a great pair of folding doors, or flood-gates, of timber, placed across the river, opening against the stream and shutting with it, but not so as to come even in a straight line, but in an obtuse angle, to resist and bear the weight of the water. In each of the flood-gates is a sluice for letting water through at pleasure. The space within the gates was built up with free-stone, big enough to receive the largest barge afloat.

In its older meaning a 'lock' was made up of bars of wood called 'rimers', set perpendicularly to the bed of the river, and 'lock-gates' put down between every two rimers. The 'lock-gates' were pulled up when required for the passage of boats.

[1] Plot, p. 386.

The first half of the seventeenth century is famous for the invention of a steam engine and other mechanical appliances by the ingenious EDWARD SOMERSET, second MARQUIS OF WORCESTER (1601–67). The carrying out of his suggestions was entrusted to his more practical associate, his lifelong assistant Caspar Kaltoff, an 'unparalleled workman'. Unfortunately such mechanical pursuits were greatly hindered by the troubles of the times in which he lived, but a hundred of his inventions were briefly described in his *Century of Inventions* written in 1655. His 'admirable and most forcible way to drive up water by fire', a steam apparatus which could raise a column of water to the height of 40 feet, seems to have been actually at work at Vauxhall from 1663 to 1670.[1]

In Oxford a contemporary mechanician of a similar type, with more leisure, but of less ample fortune, was FRANCIS POTTER (1594–1678), B.D. of Trinity College. His genius 'lay most of all to the mechanicks'. 'He understood only common Arithmetique, and never went farther in Geometie than the first six bookes of Euclid, but he had such an inventive head, that with this foundation he was able to doe great matters in the mechaniques, and to solve phaenomena in naturall philosophie.' 'He was from a boy given to draweing and painting. . . . He had excellent notions for the raysing of water; I have heard him say, that he would rayse the water at Worcester with lesse trouble, i. e. fewer . . . . . . then there are; and that he had never seen a water-house engine, but that he could invent a better. Kilmanton is on a high hill, and the parsonage-well is extraordinary deepe. There is the most ingeniose and usefull buckett-well, that ever I sawe. Now, whereas, some deep wells have wheeles for men or dogges to go within them, here is a wheele of . . . . . foot diameter wth steps (like stayres) to walke on as if you were goeing up staires, and an ordinary bodye's weight, drawes up a great buckett, which holds a barrell, and the two bucketts are contrived so that their ropes alwaies are perpendicular and consequently parallel, and so never interfere with one another. Now, this vast buckett

[1] Henry Dircks, *Life of the Marquis of Worcester*, 1863.

would be too cumbersome to overturne, to pour out the water, and therefore he contrived a board with lifts about the sides, like a trough, to slide under the buckett, when 'tis drawne up; and at the bottome of the buckett is a plug, the weight of the water jogging upon the sliding trough, the water powres out into the trough, and from thence runnes into your paile, or other vessell. 'Tis extremely well worth the seeing. I have[1] taken heretofore a draught of it. I have heard him say that he would have undertaken to have brought up the water from the springs at the bottom of the hill to the towne of Shaftesbury, which is on a waterles hill.'

Aubrey further records that he has 'many excellent good notes from him as to mechaniques etc., and I never was with him but I learn't, and alwayes tooke notes; but now indeed the Royall Societie haz outdonne most of his things, as having a better apparatus, and more spare money'.[2]

Several ingenious mechanical contrivances are associated with John Wilkins (1614–72), of Magdalen Hall, the son of an Oxford goldsmith, Warden of Wadham, and afterwards Bishop of Chester, who is noted for his scheme for a flying machine. In the Museum of the Royal Society were preserved for a time his Way-wiser, which has been described on p. 326, and his Wind-gun. The latter was composed of two barrels, one within another, to which was fitted a rod to charge it with air. At the breech where the two barrels opened one into the other was a valve to admit compressed air into the outer barrel, when the rod was driven in, and to keep it there.

Several statical and constructional problems were involved in the construction of the Geometrick Flat Floor, contrived and delineated in 1644 by Dr. J. Wallis (1616–1703) at Queens' College in Cambridge. The proposition was how to support a floor over a large area which is wider than the length of the timbers available for the joists. When he was made Professor of Geometry at Oxford, *c.* 1650, he caused a model of his

[1] Aubrey's sketch of the machine may be seen in the Bodleian in MS. Aubrey 6, f. 60v.

[2] Aubrey's *Lives*, Clark edit.

floor to be framed of small pieces of wood, representing the timbers, prepared by Mr. Rainsford, a joiner in Oxford, and put together by the Professor. Replicas of the model were made for Wilkins in 1651, and for the King in 1660. Wallis read two public lectures upon his model—one as to the construction of it in 1652, the other as to the computation of what weight every joint of it sustains, in 1653.[1] A floor in the Tower of the Public Schools was constructed according to his plan.

Wallis's floor was far surpassed by the roof of the Sheldonian Theatre, for which Wren used *main-beams* 'made of divers pieces of timber, from side-wall to side-wall, 80 foot over one way and 70 the other; whose *Lockages* being so different from any before-mentioned, and in many other particulars perhaps not to be parallel'd in the World'. An 'exact Draught' of it was published by Plot in his *Natural History*. The Sheldonian Theatre was opened on July 9, 1669.

PRINCE RUPERT (1619–82) has already been mentioned as a chemist. As a mechanic he is remembered by his Assayer to try the strength of Gunpowder. It was composed of two flat, upright, and parallel stands of brass, about 1¼ ft. high, with a shallow indenture on both their inner edges. 'Upon the base on which they stand, and between them, is placed a powder-pan. Over which a Slider, with a thin plate-spring, which plays against the said teeth, and two arms for the charging it with weight at pleasure. The stronger the powder is, it forceth the Slider to a greater height.'[2]

The next considerable advances in Mechanics in the second half of the seventeenth century are associated with the great names of the Scientific Renaissance of Oxford, with ROBERT HOOKE of Christ Church, with CHRISTOPHER WREN of Wadham and All Souls, and with WALLIS, to the last two of whom is due the correct statement of the theory of impact.

It was a period of the greatest activity: indeed the fertility of invention and variety of experiment shown within the space of a very few years are almost bewildering. The amazing achievements of Wren are unique: he was imbued with the genius of the great Florentine

[1] Wallis, *de Motu*, 1670, Book 6.
[2] Grew, *Catalogue*, p. 366.

artists, but excelled them both in science and in modesty. It is probably owing to his surpassing qualities that no Oxford man has as yet been competent to produce an adequate Life of her greatest son.

It is indeed wonderful what the first Fellows of the Royal Society did accomplish in spite of the manifold duties that were laid upon them. Hooke not only covenanted to provide new experiments for almost every occasion on which the Society met, but when, as sometimes happened, the experiments did not succeed, he was *ordered* to 'think of a way to make them succeed'. (Feb. 1666-7.)

Comets, clothes, and carriages were all topics concerning which the Oxford members of the Society were desired to 'think'. Perhaps the latter subject was suggested by the bad state of the road from Oxford to London, and the frequent absence of members from the meetings for this cause.

Dr. Wilkins and Mr. Hooke were among those who studied the mechanics of carriages in 1665-6, but when it was found that there were still defects in the construction, 'it was ordered that Dr. Wren and Mr. Hooke should join in mending what might be amiss in this chariot, and endeavour to bring it to perfection'. (March 1665-6.)

But space will not permit to give an adequate account of the very varied enterprises on which these early Masters of Mechanics were engaged. We can only print notes on a few of their contributions to Mechanical Science.

Wren and Hooke were among the early swingers of pendulums in this country. In the very first note relating to a scientific matter in the Journal Book of the Royal Society,[1] it was ordered 'that Mr. Wren be desired to prepare against the next meeting for the pendulum experiment'.

Later he tried 'by several round pasteboards, their velocity in falling' (Jan. 1, 1661-2). In February he was desired to think of an easy way for a universal measure, different from that of a pendulum, and by his researches he materially extended our knowledge of the Laws of

[1] Birch, *Royal Soc.*, i, p. 4.

Pendulums. Dr. Plot, the Ashmolean Professor of Chemistry, states that

'Amongst the new Discoveries of the *Pendulum*, these are to be attributed to him; that the *Pendulum* in its Motion from rest to rest, that is, in one Descent and Ascent, moves unequally in equal Times, according to a Line of Sines; that it would continue to move either in *circular* or *eliptical* Motions; and such Vibrations would have the same Periods with those that are reciprocal; and that by a Complication of several *Pendulums* depending one upon another, there might be represented Motions like the Planetary *helical Motions*, or more intricate: and yet that these *Pendulums* would discover without Confusion (as Planets do) three or four several *Motions*, acting upon one Body with differing *Periods*; and that there may be produced a natural Standard for Measure from the *Pendulum* for vulgar Use.'

By August 1664 pendulum questions were also being investigated by Robert Hooke, who appears to have been the first to measure the vibrations of a pendulum 200 feet long. It was attached to the steeple of St. Paul's Cathedral.

ROBERT HOOKE was one of the few mechanical geniuses who have been partly trained in Oxford, but he was 'certainly the greatest mechanick in his day in the world'.[1]

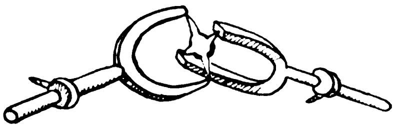
He came up to Christ Church from Westminster School in 1653, and during the great days of the study of Science in Oxford, assisted Wallis and Boyle with brilliant results. Later he became Professor of Mechanics to the Royal Society and of Geometry at Gresham College. It has been said of him that his 'mind was so prolific that there was scarcely a discovery made in his time which he did not conceive himself entitled to claim. But unfortunately, doubtless owing to congenital infirmities of mind and temper, he rarely worked out his inventions completely. No sooner had he conceived some new invention than his thoughts would rush to some other subject of inquiry. While yet a schoolboy at Westminster School he "invented thirty several ways of flying"'.[1]

Pendulum-swinging in St. Paul's became quite a

[1] Aubrey, *Lives*.

popular experiment. Sir Robert Moray, Dr. Wilkins, Dr. Goddard, Mr. Palmer, Mr. Hill, and, of course, Mr. Hooke, all visited the cathedral, some going to the top of the steeple. They found that a 200-foot pendulum made two vibrations in 15 seconds. A full report on the details of the experiments was sent by Hooke in letters to Boyle.[1]

At the same time he appears to have been busy with experiments on the velocity of falling bodies, and with the velocity of bodies shot by guns or bows, which he proposed to investigate by means of a pendulum chronograph, though with no great success (24 August, 1664). Indeed it is remarkable that he achieved as much as he did, for he was always flitting off on some new quest.



HOOKE'S JOINT, 1664.
Schott, Technica curiosa.

By means of his pendulum experiments he hit on the happy idea of measuring the force of gravity by the swinging of a pendulum (21 March, 1666). By his circular pendulum he illustrated a paper on curvilinear motion (May 1666), thus showing experimentally 'that the centre of gravity of the earth and moon is the point describing an ellipse round the sun. The clear statement of the planetary movements as a problem in mechanics dates from this remarkable essay' (*D. N. B.*). He applied the circular pendulum to watches.[2] To the same inventor is ascribed the ingenious Universal Joint that bears his name. An early figure of it, as applied to a turret clock, may be seen in Schott, *Technica curiosa*, 1664.

In 1667 Wren reported to the Royal Society his experiments on the force of gunpowder in lifting weights and bending springs; also a means of curing smoky chimneys.

[1] Boyle's *Works*, v, pp. 534-6. [2] Birch, *Hist. Roy. Soc.* ii. 97.

Bishop Sprat, speaking of the labours of the Royal Society in 1667, selects Wren's name alone for special mention. He refers to his 'doctrine of motion' which 'Descartes had before begun, having taken up some experiments of this kind on conjecture and made them the first foundations of his whole system of nature, but some of his conclusions seeming very questionable because they were only derived from the gross trials of balls meeting one another at Tennis, billiards etc. Dr. Wren produced before the society an instrument to represent the effects of all sorts of impulses made between two hard globous bodies whether of equal or different bigness and swiftness, and following or meeting each other.'

In 1668 he presented papers and showed experiments to illustrate the laws of motion deduced by him several years before from careful and varied observation of the effects produced by the collision of balls suspended under different conditions—equal, unequal, direct and differential velocities and momentum.

On this subject Newton[1] writes: 'From these laws [i. e. the laws of motion] Dr. Christopher Wren, knight, John Wallis and Christian Huyghens, who are beyond comparison the leading geometers of this age, arrived at the laws of the collision and mutual rebound of two bodies; but their truth was proved by Dr. Wren by experiments on suspended balls in the presence of the Royal Society.'

In 1670 Wren showed the Royal Society an improvement in the machinery for winding up weights by ropes from great depths.[2] An identical arrangement has recently been brought into use.

In 1679, Newton having written to the Royal Society to propose that an experiment should be made to give ocular proof of the earth's diurnal motion by letting a weight fall from a considerable height which ought to fall to the eastward of the plumb line, Wren proposed a still more effective test by 'shooting a bullet upward at a certain angle from the perpendicular round every way' to see if the bullet would fall in a perfect circle around the barrel.

[1] *Principia*, p. 20.

[2] *Royal Society Register*, bk. iv, p. 99, with diagram.

Among the problems of navigation he demonstrated how a force upon an oblique plane would cause the motion of the plane against the first mover. He explained by an instrument 'the geometrical mechanics of rowing, viz. that the oar moves upon its Thowle, as a vectis on a yielding fulcrum, and found out what degree of impediment the expansion of a body to be moved in a liquid medium ordinarily produces in all proportions', and the necessary elements for laying down the geometry of sailing, swimming, rowing, flying, and the fabrick of ships. By a special instrument he showed 'the mechanical reason of sailing to all winds', how far against the wind a ship may sail, and that the mechanical power, to which sailing is reducible, is a wedge. This instrument lay for a time in the Museum of the Royal Society.[1]

'He started several things towards the emendation of waterworks,' a subject to which his attention had been drawn when he reported on the velocity of the water flowing in the rivers of Ware in 1670.

Wren devised an engine for grinding Hyperbolical Glasses[2] (June 1669).

He also observed 'that a plain straight-edged chisel, set any way obliquely to a cylinder of wood, did necessarily turn it into a Cylindroides Hyperbolicum convexo-concavum; the several sections whereof are accurately demonstrated by the Reverend and Learned Dr. John Wallis our English Archimedes'.[3]

But in the estimate of the country generally, the savant who applied his science to the heavens rose higher in the popular estimation. ISAAC NEWTON (1642–1727) expounded his mechanical knowledge in the *Principia*, completed in 1687. Newton's Mechanics were based on the three laws of motion. He investigated the statics and dynamics of rigid bodies and fluids and created the theory of attractions—the outcome of his early theory of gravitation. As early as 1666, he believed that terrestrial gravity extended to the moon and varied inversely as the square of the distance, but owing to the inaccurate estimate he had made of the radius of the

[1] Grew, *Catalogue*, p. 364. [2] *Phil. Trans.*, No. 53.
[3] Wallis, *Mechanica, de Motu* ii. *De calculo centri gravitatis*, v, prop. 32.

earth, he found it necessary to have recourse to a second force acting upon the moon as well.

A more accurate value of the radius of the earth being available in 1679 he repeated his computations, with the result of finding that his early hypothesis was completely verified. In 1684 Newton communicated to Halley his proof that if a planet is attracted to the sun by a force that is inversely proportional to the square of the distance, the planet must move in an elliptic orbit. So important did this communication appear to Halley that he induced Newton to publish his demonstrations and arguments on gravitation in a connected form.

The first book of the *Principia*, introduced by an essay on the Science of Dynamics, treats of the motion of particles, or bodies in free space, either in known orbits, or under the action of known forces, or under their mutual attraction.

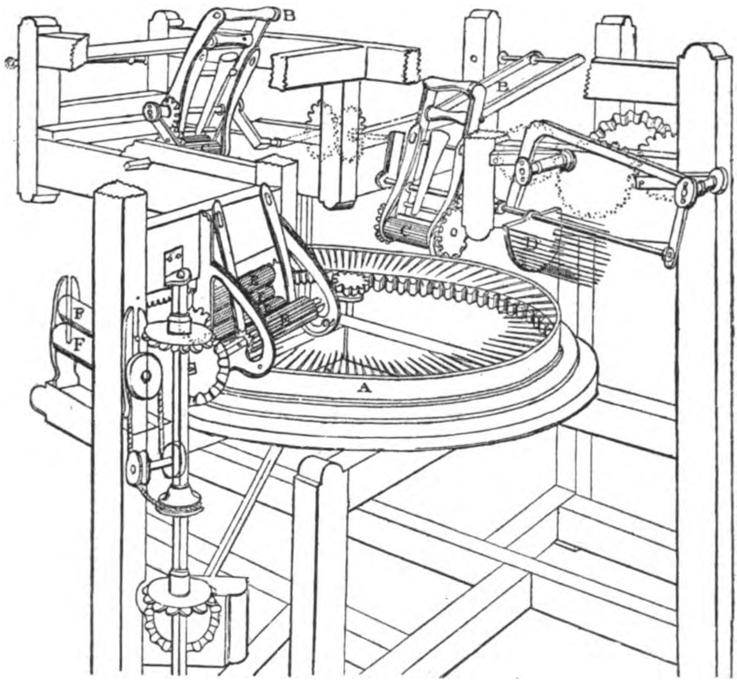
The second book is on motion in a resisting medium. The theory of Hydrodynamics is applied to waves, tides, and acoustics. The velocity of sound in air and other media was determined experimentally.

The third book explains the solar system by the theorems of the first book and presents determinations of the masses and distances of the planets and of certain of their satellites. The theories of lunar motions, and of the tides, are elaborated in particular detail, and comets are also considered as being part of the solar system.

In the *Principia* the phenomena of the solar system were shown by geometrical methods to be deducible from laws which can be demonstrated to be true by experiment on the earth, and thus 'new worlds have been brought within the scope of man's investigations'. But we must bear in mind that although Newton's methods were in the main mathematical, he would have accomplished little or nothing without the mechanical aid of the instrument makers by whose skill Greenwich Observatory had been provided with accurate measuring instruments. By means of these instruments the first three Astronomers Royal, Flamsteed (1646–1719), Halley (1656–1742), and Bradley (1693–1762), were enabled to record the relative movements of the heavenly bodies with such accuracy that Newton found ready to hand

the observations of a hundred years with which to test the validity of his conclusions.

Thenceforward the study of higher mathematics became centred at Cambridge. The best students naturally gravitated to the best teaching, and Oxford, perhaps not unwillingly, fell back.



DR. CARTWRIGHT'S 'BIG BEN' OR WOOL-COMBING MACHINE.
Gunther, Daubeny Laboratory Register, ii, p. 151.

A man who will always rank extremely high among the mechanical geniuses bred in Oxford is Dr. EDMUND CARTWRIGHT, F.R.S., who matriculated at University College in 1757, and became a Fellow of Magdalen in 1764. After taking out a first Patent for a machine for weaving (the Power Loom) in 1785, he invented a Wool-Combing machine in 1789—two inventions that have materially contributed to the industrial prosperity of

England. In 1791 Messrs. Grimshaw of Manchester contracted for 400 Cartwright looms, but soon after twenty-four had been set to work, an incendiary set fire to the mill, which was burned down. Cartwright's other mechanical inventions included the application of the treadmill to the working of cranes (1797), and a Patent for a Steam engine (11 November, 1797).[1]

His Three-furrow Plough gained him the silver medal of the Society of Arts in 1803; and in the year of his death (1823), he invented a gas explosion engine which may be regarded as the forerunner of modern gas and petrol engines, only his source of the gas was gunpowder. In 1809 he received a grant of £10,000 from the Government 'for the good service he had rendered the public by his invention of weaving'.

[1] *Phil. Mag.*, June 1798.

NOTES ON MISCELLANEOUS MACHINES IN OXFORD

A GREAT number of the machines in use during the sixteenth century are described in a large work by a member of St. John's College and of Christ Church, ROBERT FLUDD (1574–1637), the *Utriusque Cosmi Metaphysica, Physica atque Technica Historia*, dedicated both to the Deity and to James I, and published in 1617. Fludd was a medical man, who made himself master of all that was previously known about most branches of mechanics, hydrostatics, and pneumatics, about surveying and music. To these studies he added astrology and geomancy, and maintained that all true natural science is rooted in revelation. We gather that his claim to be an original inventor was small, but his great History of the Macrocosm is an important storehouse for the knowledge of the time, most methodically arranged, and admirably illustrated with beautiful copper-plate engravings by John Theodore de Bry. It must have been a most stimulating work.

APPARATUS FOR DEMONSTRATING THE MECHANICAL POWERS

86. Three brass **Pulley Blocks.** **c. 1700.**

Orrery Collection 48.

With 1-, 2-, and 3-sheaves and $1\frac{1}{4}$-inch wheels. Workmanship fine, probably by Rowley. Figure on p. 225.

'Two strong Brass Pulleys.'

No. 77, Royal Society.

87. Brass Frame with Levers and 4 Pulleys. **c. 1780.**

Oriel College.

By Nairne, London.

With box of extra weights and additional Apparatus.

88. Brass Frame with Worm-Wheel and Tangent Screw, and Inclinable Plane. c. 1780.

Oriel College

By Nairne, London.

Mounted on brass pillar 13 inches high. This model and the last are constructed on the lines of the apparatus depicted in the plates to Ferguson's *Lectures*, 1776.

89. Inclined Tramway with Pulley wheel. Before 1810.

Senior Common Room of New College.

Presented by Bishop Shuttleworth before his becoming a Master.

It is in use for passing decanters of wine between persons sitting on either side of the fireplace. The tradition that it was copied from a Colliery tramway in the North of England is probably correct.

P. N. Shuttleworth (1782–1842) became Warden of New College in 1822. He was 'not successful in the management of young men', but enjoyed a measure of popularity because 'no person of eminence came to Oxford without dining with him' (*D. N. B.*). He is (or should be) remembered by his *Specimen of a Geological Lecture*, that has been included by Daubeny in *Fugitive Poems*. It began

> In Ashmole's ample dome, with look sedate
> Midst heads of mammoths, Heads of Houses sate.

90. Inclined Tramway with Pulley wheel. 18—.

Common Room of Magdalen College.

Copied from Bp. Shuttleworth's model.

91. Cogwheels. **xivth cent.**

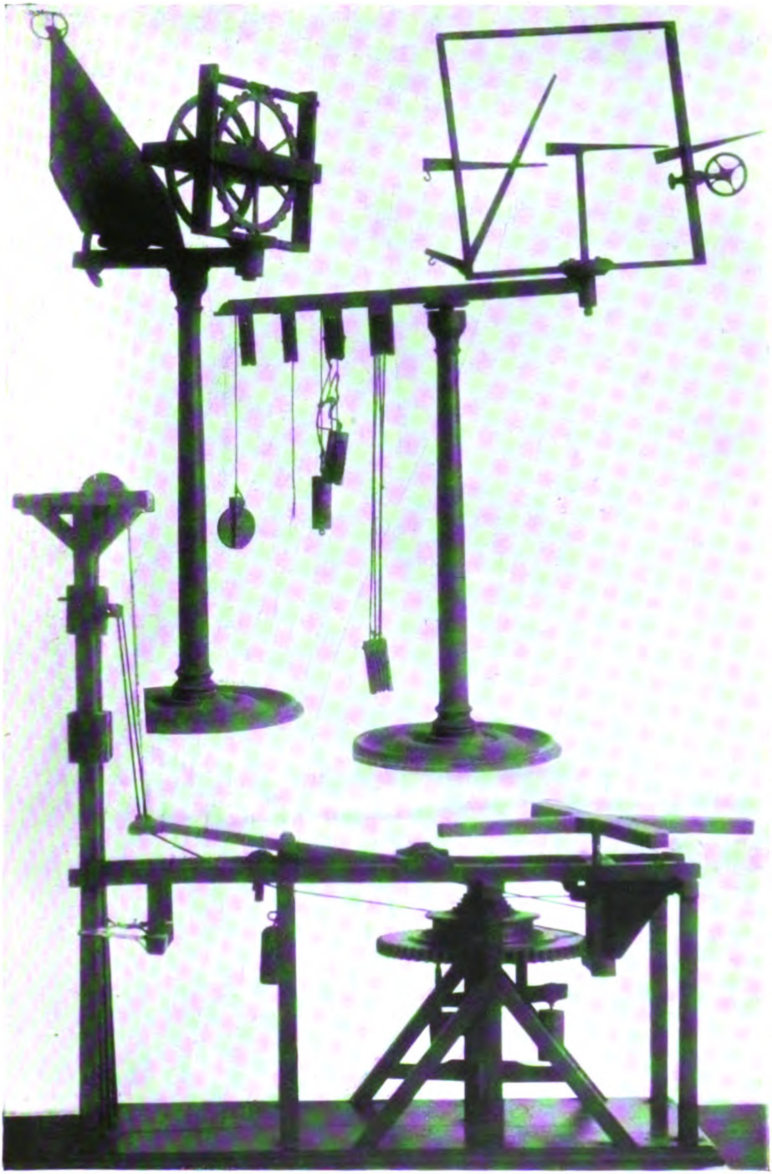
Bodleian Library.

Two wooden cogwheels for fortune-telling are inserted in the cover of MS. Digby 46. They have 13 and 24 teeth respectively, so that the smaller wheel must make 24 revolutions before the same teeth come into gear again.

92. Worm-Jack (with 3 weights). **c. 1700.**

Orrery Coll. 30.

A scientifically constructed instrument, probably by Rowley.

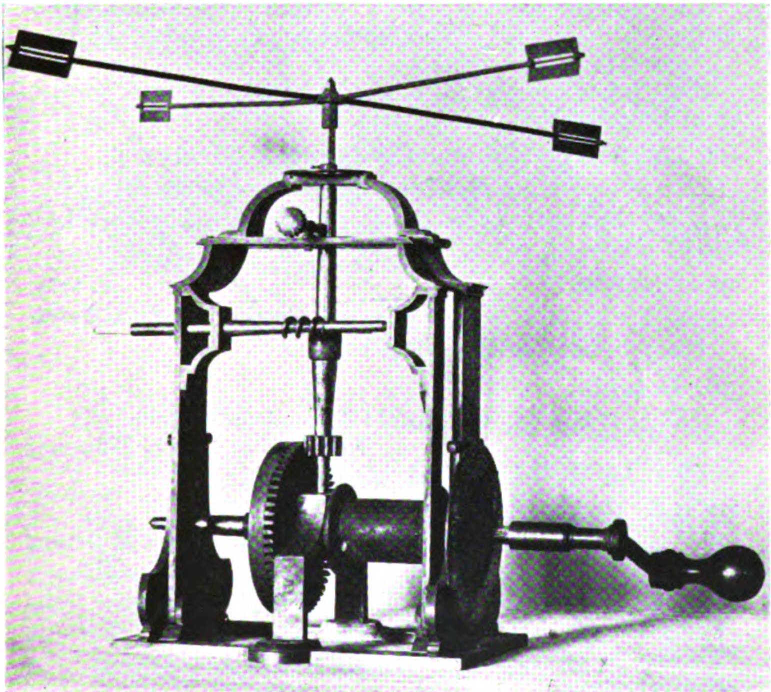


NOS. 87, 88. NAIRNE'S MECHANICAL MODELS

NO. 93. LORD LEIGH'S MODEL OF A PILE DRIVER

Oriel College

The fore-side of the Jack-frame bearing the worm is hinged to the rest of the frame in such a manner that the friction between worm and wheel can be regulated by a fine screw, and thus the speed of the instrument can be regulated. It may have been employed by Lord Orrery for driving his astronomical models.



LORD ORRERY'S WORM-JACK, *c.* 1700.

For a technical description of the ordinary worm-jack see Moxon's *Mechanick Exercises* (1677), p. 37.

93. Model of Pile Driver. c. 1780.

? Lord Leigh Collection, Oriel College.

This model recalls the illustrations to Ferguson's *Lectures*, 1776, p. 98, in which work is a description of Vanloue's curious Pile Engine which was made use of

for driving the piles of Westminster Bridge. The origin of the machine is lost in antiquity; an excellent drawing of an Italian model is shown in Leonardo da Vinci's MS. at Holkham, fol. 10^{v}.

Balances

See also p. 241.

In 1569 the Bursars of Trinity College purchased scales on losing 18^{d} over some French coins. (*Trinity College History.*)

An excellent description of the Steelyard, or *Romana*, is in Fludd's *Macrocosm*, 1617.

94. Dotchin or Chinese Goldsmiths' Steelyard.

Formerly in Coin Room, Bodleian Library.

Ivory beam 8 inches long, in original case marked 'Noll' (printed).

95. Dotchin. c. 1710.

Orrery Collection, Christ Church.

Ivory beam 8 inches long.

96. Dotchin.

No. 74 (? No. 65. Old Catal.) Ashmolean Museum.
Now in Pitt Rivers Museum.

Pres. by W. Lloyd, Keeper 1796–1815.

97–106. Dotchins.

Pitt Rivers Museum.

10 other examples, including one from the Pitt Rivers coll. No. 3837 and one from the Pitt Rivers coll. No. 3180. A Chinese example measures 2 ft. 5 in. in length.

Steelyards.

Pitt Rivers Museum.

107. Old Dutch S. Pres. by H. Balfour.

108. Indian S. Wooden yard 1 ft. 6½ in. long; with horn fittings.

109. Shropshire S. 11-inch iron yard.

J. Partington collection.

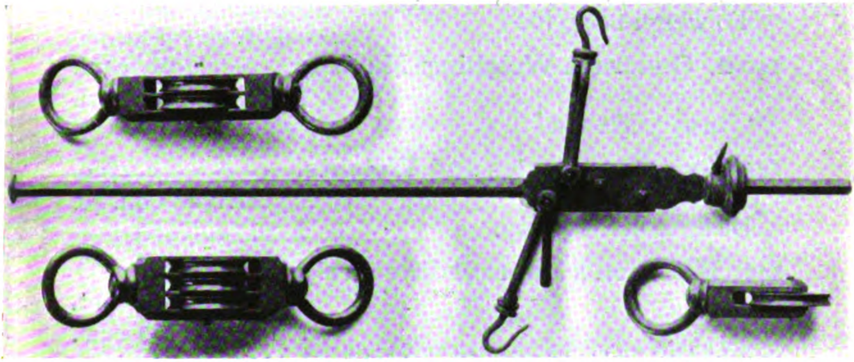
110. Irish S. 17th cent. Described in *Kilkenny Archaeol. Journ.* ii. 1858.

Pitt Rivers coll. 226/12099.

111. Breton S. Two from Carnac, pres. by H. Balfour.

112. Brass Steelyard. Length $13\frac{1}{2}$ inches. **c. 1700.**
Orrery Coll. 44.

'Joh. Rowley fecit.'



Lord Orrery's Pulley Blocks (No. 86) and Steelyard (No. 112).
By Rowley.

113–137. Bismers.
Pitt Rivers Museum.

25 examples from various localities including Norway, Faeroe Isles, Orkney, Shetland, Stockholm, Finland, Sweden, Akyab, Madras, Burmah, and numerous primitive forms from Malaysia. A large wooden example from Malabar has ornamental brass ends: it is 5 ft. $9\frac{1}{2}$ in. long, with brass pins indicating weights in palams.

138. Bismer, used in Norfolk. **1797.**
Pitt Rivers Museum.

Pres. by H. Balfour.
The yard is made of a flat piece of wood, $9\frac{1}{2}$ inches long and slotted throughout its length. Graduated to weigh from 1 to 6 lbs.

139. Spring Balance. **'Mediaeval.'**
Pitt Rivers collection No. 9/11363.

From Clermont-Ferrand, Auvergne.
Iron; shaped like a quadrant, $3\frac{1}{2}$ in. radius: marked to weigh to xvi 'lbs'.

140. Spring Weighing Machine. **19th cent.**
Pitt Rivers Museum.

By 'Braby, Lambeth'.
Purch. at Nettlebed, Oxon.
To weigh to 36 lbs.

140 a. Quadrant Weighing Machine. **19th cent.**
Pitt Rivers Museum.

'BRABY, MAKER.'

141. Jewellers' Scales and Weights. **c. 1700.**
Orrery Coll. 40.

Beam 4 inches long.

142. Harrison's Improved Sovereign Balance.
19th cent.
Pitt Rivers Museum.

'Warranted correct. To weigh and gauge Sovereigns and half Sovereigns. Being so exact that no Counterfeit can possibly go through the Gauge of sufficient weight to turn the Balance.'

TIME-KEEPERS

Several of the various mechanical contrivances for measuring the lapse of time are illustrated by instruments in the Oxford Collections.

Among the earliest methods for the measurement of short intervals of time were those of the water-clock and the sand glass. The origin of both of these primitive clocks is lost in antiquity, and yet both have on many occasions interested the boyhood of great men and are still in use to-day.

A Water-Clock, constructed by Sir Anthony Cope at Hanwell, was described by Plot as having a 'pseudo-perpetual motion'.

A similar principle, namely, the regular flow of matter through a small orifice, was employed by the ingenious JOHN JONES, LL.B., Fellow of Jesus College, in the construction of his Pneumatic Clock, 'which moves by the air equally expressed out of bellows of a cylindrical form, falling into folds in its descent, much after the manner of paper lanterns: these in place of drawing up the weights of other clocks, are only filled with air,

admitted into them by a large orifice at the top, which is stop'd up again as soon as they are full with a hollow screw, in the head wherof there is set a small brass plate, about the bigness of a silver halfpenny, with a hole perforated scarce so big as the smallest pins head: through this little hole the air is equally expressed by weights laid on the top of the bellows, which descending very slowly, draw a clock-line, having a counterpoise at the other end, that turns a pully-wheel, fastened to the arbor or axis of the hand that points to the hour: which device, though not brought to the intended perfection of the inventor, that perhaps it may be by the help of a tumbrel or fuse, yet highly deserves mentioning, there being nothing of this kind that I can find amongst the writers of Mechanicks.'[1] (Plot.)

The regular rate of the combustion of candles was probably well known to the early inhabitants of the city, and even King Alfred is said to have measured the lapse of time by such means.

Time-Pieces

Primitive Instruments

143. Water-Clock. **1901.**

Pitt Rivers Museum.

In use in Lower Siam. Diam. $2\frac{1}{2}$ inches.

A coco-nut shell floating on water, for timing cock-fight bouts. Similar instruments are widely used in the East.

144–5. Water-Clocks (2). **Modern.**

Pitt Rivers Museum.

a. Diam. 5 inches. Used by Malay boatmen for measuring the duration of a watch at sea. It consists of a half coco-nut shell, with a perforation in the bottom. It is floated in a bucket of water.

b. Diam. $4\frac{3}{8}$ inches. Used by native physicians in Malabar.

146–151. Water-Clocks. **Modern.**

Pitt Rivers Museum.

a. Diam. $6\frac{3}{8}$ in. Sinks in 55–58 minutes. Mirzapur.

[1] Pneumatic clocks were in use in Paris in 1875.

b.	Diam. $6\frac{5}{8}$ in.	Sinks in	27	minutes.	India.
c.	„ $5\frac{5}{8}$ in.	„	$27\frac{1}{4}$–$28\frac{1}{4}$	„	India.
d.	„ $4\frac{5}{8}$ in.				Madras.
e.		„	10	„	Algeria.
f.	„ 6 in.	„	27	„	Mandalay.

d and *e* were used for measuring irrigation periods.

In the Algerian Sahara water-clocks are used for the purpose of measuring the time that the water of a well belonging to several proprietors has been flowing over their respective rice fields. The water-clock consists of a copper bowl some 7 inches in diameter and 5 inches in depth, which acts on the principle of an hour-glass. This primitive clock is floated in a bucket filled with water which percolates into the bowl through a small hole in the bottom, from which a narrow tube rises to regulate the flow. As soon as the bowl is full enough to sink, it is removed from the bucket; its contents are emptied out, and it is then immediately floated again on the surface of the water by the man who is left in charge of it. At stated intervals, measured by the number of times that the water-clock has had to be emptied, the time is shouted out by the man controlling it, who is usually stationed on the top of some building. (King, *Geogr. Journ.* Nov. 1917.)

f was used in the Emperor's Palace at Mandalay to measure an hour of 24 minutes. 'The hour is sounded by the attendant or watchman on a large gong, and every time the bowl sinks, a bead is drawn along a wire to act as a record of hours elapsed.' The wired beads accompany the water-clock.

Sand Glasses

In the sixteenth century hour-glasses were used to set limits to the length of academic disputations in Oxford. That this practice was continued until the time of the Commonwealth is indicated by an amusing story about Dr. Kettel, the President of Trinity who in the Hall of Trinity 'sate with a black fur muff and an hour-glass before him to time the exercise'. He used always to take his 'hower glasse' to his lectures and exercises in the Hall 'and one time, being offended at the boyes, he threatned them that if they would not

doe their exercise better he would bring an hower-glasse two howers long.'[1] One day when Cromwell was in possession of Oxford, a halberdier rushed in, and, breaking the hour-glass with his halberd, seized the Doctor's muff and threw it in his face. The Doctor, a man of great physical strength, instantly seized the soldier, and the halberd was carried out before him in triumph. This story is thus narrated by Dean Aldrich, but strict chronologists[2] will have it that the Doctor died in 1643, three years before the surrender of Oxford. But the information concerning the use of the hour-glass at that time is probably correct.

A '**3-hours glasse**' was purchased for 2*s.* 8*d.* for the Bodleian Library in 1652.

Bodleian Accounts.

152. Hour-glass.

Pitt Rivers Museum.

From Kennington, near Oxford.

The sand in this glass took 52 minutes to run.[3]

153–7. Hour-glass.

Three English examples in the Pitt Rivers Museum.

One Florentine example in ditto.

158. Hour-glass.

Ashmolean Museum.

Lamp and Candle Clocks

159–163. Clock Lamps. (5)

Pitt Rivers Museum.

English Clock Lamp.		**18th cent.**
Swiss „ „		
2 Flemish „ „		
Austrian „ „		**18th cent.**

164. Candle-Nut Kernels strung on a string. Modern.

Pitt Rivers Museum.

Used as a time-piece in Hawaii. The string is two feet in length.

[1] Aubrey, *Lives.* [2] Murray, *Oxf. Handbook*, p. 58, 1894.
[3] Timed at my request by Mr. G. R. Carline, who has been good enough to supply information on the instruments in his charge.

165. Candle-Nut Kernels. **Modern.**

Pitt Rivers Museum.

From New Guinea.
Strung on the mid-rib of a palm leaf.

166. Time Incense Candle. **Modern.**

Pitt Rivers Museum.

Chinese.

167. Time Candle. **Modern.**

Pitt Rivers Museum.

Graduated in 10 divisions and used in Roman Catholic Churches in London.

CLOCKS

Wel sikerer was his crowing in his logge,
Than is a clokke or an abbey orlogge.

Chaucer, *Nonne's Priest's Tale.*

As civilization advanced, the even running of machinery must have impressed any thoughtful observer. The regularity of the rotation of water-wheels, or of wind-mills under a constant driving force, was obvious, and no doubt some such machine commended itself to Gerbert, afterwards Pope Sylvester II, at Magdeburg in A.D. 996 as a possible clock. His clock was driven by a weight.

By the eleventh century weight clocks had come into general use in the monasteries of Europe as an adjunct for securing punctuality at prayers. It is suggested that they may have been made without dials, merely to strike bells at intervals. The addition of a dial, and a fairly complicated one too, was the achievement of our Oxford savant, Richard of Wallingford.

Regularity in clock movements was only secured in 1657, when Huygens first brought the pendulum clock into general use. Nine years later the Huygenian pendulum was so much improved by Hooke,[1] that in 1680 it was introduced in clocks.

Watches and Chronometers.

For portability a spring was substituted for the weight by Peter Hele of Nuremberg about 1500, but no satisfactory means of equalizing the pressure of an

[1] *Phil. Trans.*, 1666.

unrolling spring was found before 1525, when Jacob Zech of Prague introduced the fusee.

Watch glasses are said to have been first used about 1600, although watches were not as a rule carried in a pocket before 1625. It is consequently not surprising that they should not have been remarkable for the regularity of their going, apart from the inherent defects of their construction. And it was only when portable clocks and watches were found to be necessary for the determination of longitude at sea, that they came to be treated as scientific instruments.

At Oxford WREN devoted some time to the consideration of means to keep the motions of watches equal,[1] in reference to longitude and astronomical uses, but in this field he does not appear to have met with the success of his contemporary ROBERT HOOKE, a person of 'prodigious inventive head', and 'of great vertue and goodness'. (Aubrey.) His work on pendulums has already been mentioned.

His contribution to Horology has been abstracted by Britten.

'There is no reasonable doubt that Hooke invented the **balance spring**. He thoroughly investigated its properties about 1658, and propounded the whole theory in the sentence, *Ut tensio, sic vis*, meaning that the force is proportionate to the tension. Hooke proposed to patent his discovery, and, in his own words, "Sir Robert Moray drew me up the form of a patent, the principal part whereof, viz. the description of the watch, is his own hand writing, which I have yet by me; the discouragement I met with in the progress of this affair made me desist for that time". Several watches were made by Tompion under Hooke's supervision. One of the first to which the balance spring was applied, Hooke presented to Dr. Wilkins, afterwards Bishop of Chester, about 1661.'

The final volute form of the spring was evolved only after many experiments. Straight springs, and some in the form of a pothook, were among the earlier essays.

[1] To Wren was also due the suggestion of the use of black lead as a lubricant, as a better means than oil for preserving the pivots of the wheels of watches or clocks from grating, or wearing out (12 Feb. 1661–2).

A watch, subsequently made for Charles II, was inscribed, 'Robt. Hooke, inven: 1658, T. Tompion, fecit, 1675.'

In 1660 Hooke devised a pendulum timekeeper, for ascertaining the longitude at sea, which was tried in 1662. He subsequently proposed a compensation pendulum in the form of a rhomboid, the outline being of steel and the long horizontal diagonal of brass. This form, being wider than it was long, was considered to be unpractical. Troughton afterwards constructed a pendulum in which the rod was a series of small rhomboids arranged to compensate on Hooke's plan.

Hooke invented the **anchor escapement** for clocks about 1675, and it is stated that he also devised a wheel-cutting engine. Among his conceptions for a marine timekeeper was one with two balances geared together, the idea being to avoid the effect of external motion. It is stated that this timekeeper had an escapement resembling the duplex.[1]

Neither Wren nor Hooke was, however, completely successful in his endeavours, and it remained for JOHN HARRISON in 1735, in response to the rewards offered by the Government in 1713, to adapt the principle of the unequal expansion and contraction of different metals, to compensate the balance spring for changes of temperature.

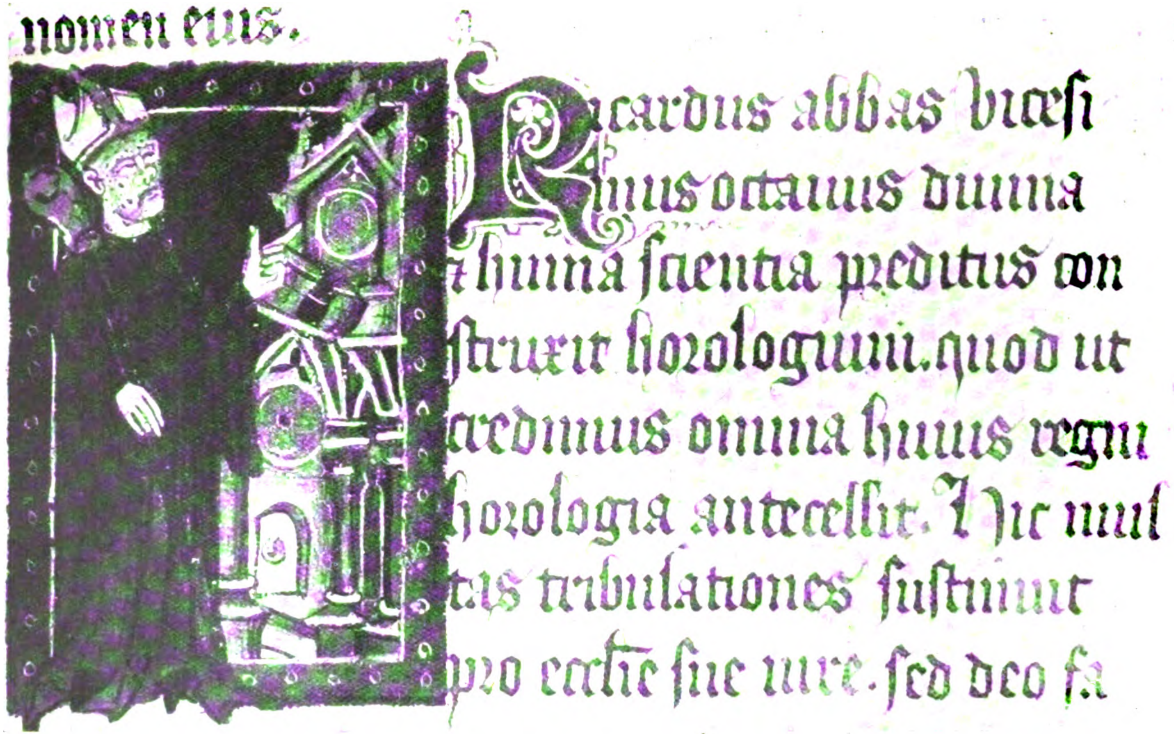
Since then the notable improvements have been the Lever Escapement of MUDGE, 1765, the Helical Balance Spring of ARNOLD, the Spring Detent Escapement of EARNSHAW and ARNOLD, *c.* 1780, and finally Earnshaw's Compensation Balance, 1782.

There are no specimens of early chronometers in Oxford now, but four of Harrison's chronometers are in the Royal Observatory, Greenwich; and the one used by Captain Cook during his Voyage of Discovery in 1772–5 may be seen in the Museum of the Royal United Service Institution.

LARGE CLOCKS

According to one account the first horologe in this country was constructed in 1326 by Richard of Wallingford, Abbot of St. Albans. It was certainly an advance upon the arrangements for bell ringing at regular

[1] Britten, *Former Clock and Watch Makers.*



RICHARD OF WALLINGFORD AND HIS HOROLOGIUM, 1326.

intervals that had been in use in many monasteries during the twelfth and thirteenth centuries. Probably Wallingford constructed a clock with a visible dial, though of the nature of the internal mechanism we are ignorant.

He is represented in the illumination on f. 20 of MS. Nero D. vii in the British Museum, which we reproduce.

168. Turret Clock. **1505.**

Magdalen College Tower.

Made by William Este of Abingdon, *mason*
Louis Foose „ „ , *painter*
Martin Wylliamson of Oxford, *beer-brewer*
who contracted to make a clock of new iron, both house, hammer and wheels, and bars and hands to the dial, by Allhallows next, the clock to go sufficiently and truly for a year and a day, and all repairs within the first year to be at their expense, for the sum of £10.[1]

In 1505 the bells were removed to the new tower. In 1516 one of the Fellows, John Symonds, was paid fifteen shillings for taking care of the clock. Minor repairs costing 6*s*. 8*d*. in 1602, were undertaken by Triumph de St. Paul.

In 1908, an old clock was replaced by one by John Smith & Co. of Derby. The old clock is preserved on the first floor of the Great Tower.

169. College Clock. **c. 1673–1870.**

Wadham College.

By Christopher Wren.

This clock is mentioned for the first time in the *Convention Book* on March 27, 1673, when a yearly charge of 6d was 'putt on' every one's name 'as a reward for cleansing the marble in the Chapple and ordering the clock'. According to tradition it was a present from Sir Christopher Wren, who is supposed to have designed its mechanism. It lasted till 1870, when, being quite worn out, it was replaced by a new one. The old works are preserved as a relic in the ante-Chapel, and the original f ce of the old clock is retained unaltered. The armorial bearings, three crosses crosslet or, in an upper spandrel, confirm the tradition that Wren was the donor.[2]

[1] Macray, *Magdalen Register of Fellows*, i, p. 34.
[2] T. G. Jackson, *Wadham College*, p. 158.

170. Turret Clock. **between ? 1810–54.**
Christ Church.

The public clock in Tom Tower (?) was made by Benjamin Lewis Vulliamy (1780–1854) of 68 Pall Mall, clockmaker to the ruling sovereign. He was noted for the exactness and excellent finish of his work and was five times master of the Clock Makers' Company. He wrote a pamphlet on the construction of the dead-beat escapement for clocks, advocating the turning of the pallets for ensuring greater exactness. (Britten.)

Portable Clocks and Watches

171. Portable Striking Clock.
Ashmolean Museum.

By M. S.

The Movement is mounted in a glass cylinder under an ornamental domed and perforated top. Metal-work mounting of brass, gilt and engraved. Height 5 in., diam. 2½ in.

172. Oval watch. **1613.**
Ashmolean Museum.

By Michael Nouwen (*fl.* 1600–20).

173. Circular gold watch set with turquoises. **c. 1640.**
No. 373, Ashmolean Museum.

Pres. by Sir Sam. Hellier, Bart.

Described in the old catalogue as having been worn by Queen Elizabeth, but really the work of Edward East (1610–73), watchmaker to Charles I, and one of the ten assistants named in the Clockmakers' Charter in 1631.

174. English watch. **c. 1650.**
Green Coll., Ashmolean Museum.

By R. Quelch of Oxford.

175. Oval watch. Brass gilt.
No. 374, Ashmolean Museum.

Pres. by Sir S. Hellier.

A **Token** stamped 'Joseph Knibb, Clockmaker in Oxon', **c. 1666** was dug up under the Library of Magdalen College in 1921.

176. Watch.

No. 375, Ashmolean Museum.

By David Perry, at Fleet Bridge.

177. Oval silver watch with gold dial.

No. 377, Ashmolean Museum.

Pres. by W. Bragge, 1824.

Dr. Schomberg, a Reading physician, acquired it about the middle of the eighteenth century with a memorandum stating that it once belonged to Oliver Cromwell.

178. Clock.

Ashmolean Museum.

By Bréguet (1747–1823).

The escapement is placed in a tourbillon or revolving chamber, a device invented by him to counteract the effects of change of position.

Advertisement of G. S. Green, Watch maker in Oxford, 1758

At the Automaton Laboratory, Confronting the Portal of All Souls College in Oxford, are fabricated and renovated, Trochiliack Horologes, portable or permanent, linguaculous or taciturnal: whose circumgyrations are performed by internal spiral elasticks, or external pendulous Plumbages; Diminutives, simple or compound in Aurum or Argent Integuments.[1]

Observatory Clocks

Bernhard Walther was the first to use clocks driven by weights for observatory purposes.[2]

Tycho also had clocks, but did not depend upon them, partly on account of their variable rate. He had two placed by the side of his mural quadrant.

Hooke's Pendulum Clock. **Oct. 1669.**

Astronomical clock with a 14-foot pendulum and a 3 pound bob. The amplitude of vibration was 'not above a degree' and it was to go for seventy weeks.

Birch, *Royal Soc.* ii, p 398.

[1] MS. note inserted opposite Title-page of Richard Holland's Explanation of M. Gunter's Quadrant, As it is enlarged with an Analemma. Oxford 1676.

[2] *Scripta math. J. Regiomontani*, 1544, f. 50.

179. Astronomical Clock. **c. 1773.**

Radcliffe Observatory.

By John Shelton, London. It cost £6 6*s*.

Shelton's place of business was in Shoe Lane. He fl. 1720–66. This clock is represented in the view of the interior of the Observatory, in Ackermann's *Oxford*.

180. Astronomical Clock. Gridiron Pendulum. c.1770.

Radcliffe Observatory.

By John Shelton, London.

This clock used as a transit clock has been in almost continuous going since 1774. A small notch on the right-hand side of the dial was for a mechanism by which hand-pressure could be kept up during winding, thus obviating the risk of stoppage. The thermometer in the clock case is by J. Troughton. For its rate in 1774, see Rambaut, *Monthly Notices R. A. S.* 1900, p. 271.

Two Astronomical Clocks with Gridiron Pendulum.

17—.

Royal Society.

By Shelton.

Astronomical Clock.

Royal Society.

By Shelton.

Employed at Transits of Venus, at Schiehallion, and by Capt. Parry and Sabine.

181. Astronomical Clock. **c. 1790.**

Radcliffe Observatory.

By Chas. Haley, 7 Wigmore St., London.

This clock, formerly the property of the Rev. W. R. Dawes, was bequeathed to the Chancellor, Masters, and Scholars of the University of Oxford by Sir Henry Acland, Bart., Radcliffe Librarian, and was deposited in the Radcliffe Observatory in 1901. Charles Haley (*fl.* 1785–1800), the patentee of a remontoire escapement for chronometers, was one of the experts appointed by the Select Committee of the House of Commons to report on Mudge's chronometers in 1793.

182. Astronomical Clock. **c. 1830.**

Radcliffe Observatory.

By Arnold and Dent. With a dead-beat escapement

and a Mercurial pendulum: the reservoir is of iron. In 1840 its going was frequently checked on being wound up. This defect was remedied by Mr. Dent.

On Dec. 23, 1839, the Clock was removed to the new Transit Room.

183. Astronomical Clock. **? 1876.**

University Observatory.

By Reid of Newcastle-on-Tyne.

See Pritchard, *Monthly Notices R. A. S.*, Nov. 1878.

Two Chronometers. **c. 1772.**

Royal Society.

By Arnold. They accompanied Capt. Cook on his Voyages.

John Arnold was a Cornishman (*b.* 1734) who, after serving his apprenticeship with his father, a Bodmin watchmaker, and after a brief visit to Holland, established himself at Devereux Court, Fleet Street. One of his first acts was to make an exceedingly small half-quarter repeating watch, which he had set in a ring and presented to His Majesty George III in 1764. The whole movement was only $\frac{1}{3}$ inch across! It is described in detail in the *Annual Register* for 1764.

The Royal Society chronometers embodied Arnold's initial ideas of chronometer construction, to which he was probably stimulated by the reward offered by Parliament for a good timekeeper. One of his first productions was a chronometer which Captain Cook took with him in the *Resolution* on his second voyage in 1772. Two other timekeepers of Arnold's were on board the *Adventure*. The two which are now the property of the Royal Society have plain circular balances with flat balance springs acted on by a compensation curb; the escapements are a compound of the lever and the spring-detent, and they beat half-seconds, the workmanship being very rough compared with the finish exacted in the present day. It seems certain that a timekeeper of Larcum Kendal, which was also carried on the *Resolution*, performed better than those of Arnold.[1]

[1] J. U. Poole quoted from Britten, p. 129.

The shortcomings of his two instruments incited Arnold to do better. He devised his helical form of balance spring and a new form of compensation balance. In May 1782 he patented his improved detent escapement, which is practically the chronometer escapement still in use to-day.

184. Chronograph. ? 1878.

Radcliffe Observatory.

Formerly employed for receiving Greenwich Mean Time by telegraph. Cf. Main's *Report* for ? 1878.

HYDROSTATICS

The only one of the ancients who really stands out in the public estimation as having made any contributions of real value to the theory of hydrostatics was ARCHIMEDES (*b.* 287 B.C.), whose Spiral Pump, Burning Mirrors, with the circumstances of his joyful cry, 'Eureka! Eureka!' and his tragic death have combined to fix an indelible impression in the mind.

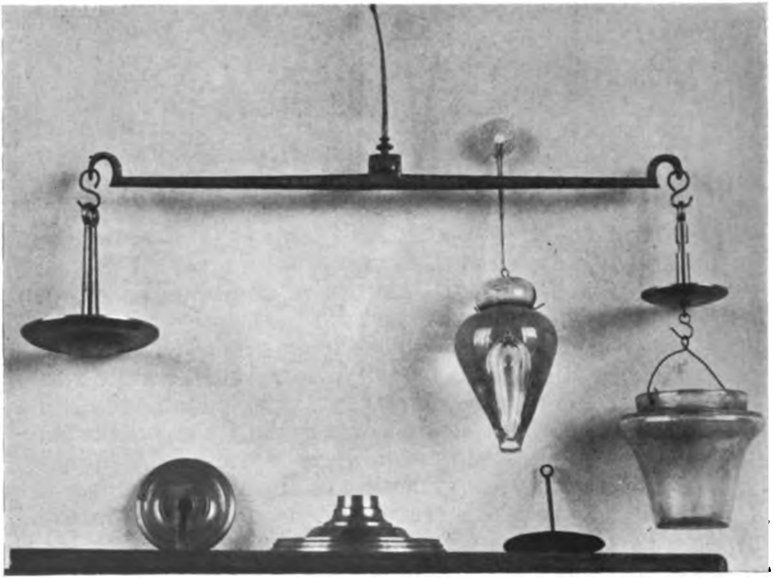
From him doubtless our early hydrostaticians drew their inspiration. The first of whom I have a note was THOMAS HARIOT (1560–1621) of St. Mary's Hall, who will be again mentioned in connexion with the telescope. He published next to nothing in spite of his pupil Sir W. Lower's warning, that by not publishing he might lose the priority of his 'rarest inventions'. In 1601 he taught Lower 'a curious way to observe weight in water', which was afterwards published by Ghetaldi in 1603, and doubtless some idea of his work might be gained from a volume of his MSS. on mechanics and hydrostatics in the British Museum. His drawing of a **Hydrostatic Balance** is the first known to have been made by an Oxford man. Addit. MS. 6788, f. 231. The date might have been about 1604.

In 1617 many of the experiments of Archimedes and Heron were presented in a popular form by ROBERT FLUDD of Christ Church in his *Macrocosmos.*

Specific weights of many substances were determined by Robert Hooke, *c.* 1665, and by ROBERT BOYLE.

The latter's description of experiments illustrating the Laws of fluid equilibrium was presented to the Royal

Society in May 1664, and published under the title of *Hydrostatical Paradoxes made out by new Experiments* in 1666,[1] illustrated with a plate of the apparatus used. Boyle's predecessor, Pascal, did not seem to have been very desirous that others should repeat his experiments, for he 'supposes the phaenomena he builds upon to be produced fifteen or twenty foot under water. And one of them requires, that a man should sit there with the



HAWKSBEE'S HYDROSTATICK BALANCE, *c.* 1710.
St. John's College.

end of a tube leaning upon his thigh; but he neither teaches us, how a man shall be enabled to continue under water,[2] nor how, in a great cistern full of water, twenty foot deep, the experimenter shall be able to discern the alterations, that happen to mercury, and other bodies at the bottom.' Boyle's new experiments were suited

[1] *Works*, ii, p. 414.
[2] For a picture of a diver walking about under water with an air-pipe to the surface, see Robert Fludd, *Macrocosmos*, 1617, i, p. 419.

NO. 186. COVENTRY'S HYDROSTATICK COUNTERFEIT COIN DETECTOR

All Souls College

for performance on a lecture table. Unfortunately none of his apparatus has survived.

185. Hydrostatick Balance. **c. 1710.**

St. John's College.

On the model of the instruments made by F. HAWKSBEE of Vine Office Court, Fleet St., in box with flat disk-shaped counterpoises, glass weight for determining the specific gravities of liquids, and a glass bucket. Believed to have been bequeathed by Pointer, who matriculated 1741, aged 16, and died 1796.

Cf. fig. in Harris's *Lexicon Technicum*, 1710.

Hydrostatic Balance.

Royal Society.

By Ramsden, with Weights by Robinson.

Pres. by Lady Banks. *Phil. Trans.* lxxx, p. 340.

186. Hydrostatick Counterfeit Coin Detector.

c. 1760.

For many years in the Bursary of All Souls College.

By John Coventry of Red Cross Street, Southwark.[1]

A convenient adaptation of the Hydrostatick Balance which is housed in a fan-shaped mahogany case, so as to be partially fool-proof. The printed *Directions for Use* affixed to the instrument tell us that one end of the balance-beam carried a light brass plate, shown in the figure, for weighing in air; and from the centre of the plate was hung a loop of horse-hair for fixing coins, that were to be weighed in water. The other end of the balance-beam carries a counterpoise. Weighings were read by noting the position of a pointer fixed to the middle of the beam, over 'Air' and 'Water' Scales.

The 'Directions for use' explain how the measure of the adulteration of silver and gold coins may be found, that of gold coins being deduced in terms of 'shillings debasement'.

[1] The Warden of All Souls, to whom I am indebted for the sight of this instrument, has not only conjecturally restored the *lacunae* in the Instructions for Use, but has found that J. Coventry flourished in 1735–1812, *D.N.B.*

DIRECTIONS FOR USE.

PLACE your PIECE on the Brass-plate, and the Index will point out its true Weight on the AIR SCALE.

If you suspect your *PIECE* to be adulterated, wipe it clean and fixing it in the Horse-Hair Loop, gently immerge it in a glass of Water, so that it touch not the Sides; and the Index will rest (IF STANDARD) against the same Division on the *W*]ATER SCALE, as before it did on the AIR SCALE: other-*wise*] your PIECE is adulterated nearly to the Rate of Four *Shill*]ings and six-pence (if with COPPER; but Six Shillings *must b*]e allowed if with SILVER) for every Division now found *deficient*] from what it before weighed on the AIR SCALE.

Ex]ample, I have an Eighteen Shilling PIECE[1] of a *doubtful fineness*] which is its full Weight in Air, but immerged as *aforesaid wants*] four Divisions (or one Shilling)[2] of the same Weight *in water*] ——. Now as each Division deficient is Four Shil-*lings and six*-]pence when adulterated with COPPER it prove[*s my PIECE all*] bad, viz. all Copper. Again, *I have an*] Eighteen Shilling PIECE, suspected to be adulter-*-ated with silv*]er, which has its full Weight in AIR, but wants *one division*] when tried in WATER; therefore as one Division *deficient is*] Six Shillings Debasement when with SILVER [*it proves that my*] PIECE has only Twelve Shillings in GOLD; and [*so accordingly*] for any Deficiency in any other Piece.

An instrument in use during the same period, though constructed on a different principle, was Bradford's Hydrostatical Instrument, which was also provided with 'Air and Water scales'.[3]

Instrument for determining Specific Gravities of Liquids. **1793.**

No. 52, Royal Society.

By Schmeisser. See *Phil. Trans.*, 1793, p. 164.

[1] What 'an Eighteen shilling piece' is, appears from a list of the then current gold coins, pasted in a box (the property of Professor Sir Charles Oman, K.B.E.) containing a balance (George II or early George III) for weighing coin. This list includes a number of Foreign Coins in circulation (besides Guineas and half-Guineas); amongst them are the Spanish Moidore of 27/- and the half-Moidore, the French Pistole (Louis d'Or) of 17/- and the half-Pistole, and 'The Portugal Piece' (6000 reis), its half, and its quarter, the latter being marked 18/- and being clearly the Piece in question. One of the Weights in the box is stamped 18/-. (Note contributed by the Warden of All Souls, from information from Sir C. Oman.)

[2] The meaning of this phrase is not clear.

[3] Figure in Chambers' *Cyclopaedia*, 1789.

Hydrometer

'After having made several fruitless trials with Ivory, because it imbibes spirituous Liquors, Mr. Clarke, Turner and Engine Maker of York Buildings, Water-works, made a copper Hydrometer.' (Desaguliers, p. 233.)

Boyle's Hydrometer. **7 May, 1662.**

'Mr. Boyle produced a glass for trying the difference of the strength of corrosive liquors.' The hydrometer is not now extant. It was made with two bulbs, as in modern instruments, a small terminal bulb with mercury ballast and a larger float bulb.

Hydrometer.

No. 64, Royal Society.

By Fordyce.

Hydrometer.

No. 79, Royal Society.

By Dicas.

Barometers

That air has weight was shown early in the seventeenth century by means of a column of water sustained by atmospheric pressure. The earliest experiments in this direction seem to have been made by Galileo about the year 1602. They were repeated by his pupil Evangelista Torricelli (1608–47), who undoubtedly constructed the first barometer a year after the death of his great teacher, but by failing to describe its applications as clearly as his master would have done, left the honour of setting them forth to Pascal, to whom are also due many experiments on the pressure exerted by fluids.

Once again, however, did the leaning tower of Pisa contribute to an important scientific discovery. Claudio Beriguardi, for carrying his barometer up the tower, was rewarded by the discovery that the Torricellian column stood higher at the base of the tower than at its summit.[1]

Robert Hooke invented the 'wheel barometer', the 'double barometer', and the 'marine barometer' (*Phil.*

[1] Antinori, *Saggi dell' Accad. del Cimento*, 1841, p. 29.

Trans. xxii. 791). To BOYLE the invention of a barometer is attributed by Plot, in which a hollow glass sphere was balanced by a metal counterpoise.

About the year 1657 Wren is believed to have been the first person in England to think of applying a barometer to detect the influence of the Moon on atmospheric pressure. To test this idea Boyle fitted up a barometer in his chamber in Oxford, and 'happen'd to discover the use of it in relation to the Weather'.[1]

BOYLE appears to have been the first to apply the word 'Barometer' to instruments that had been generally known as 'glass-canes' filled with mercury; and in the first volume of the *Philosophical Transactions*, p. 153, this instrument is mentioned as 'first made publick by that Noble Searcher of Nature, Mr. Boyle'. He is said to have made divers barometric observations as early as 1659 or 1660, 'before any others were publick', and there is no doubt but that his published observations excited 'stupious Naturalists to a sedulous prosecution of the same'; an excitement that has continued even till the present day.

In 1663 Boyle proposed to the Royal Society that two 'canes with quicksilver' might be kept, one at Gresham College, the other by himself, in order to observe how they would vary, as to the ascent and descent of the quicksilver in several weathers; such rising and falling having been previously observed by Hooke.

In the following year Torricellian experiments were actively prosecuted, Hooke going to the top of the steeple of St. Paul's for the purpose. He found that the mercury stood $\frac{1}{2}$ inch lower at the top than at the bottom of the steeple.

In the summer of 1665 Boyle continued his barometer observations by comparing the readings of two instruments, one at Oxford and the other at Stanton St. John, four miles off.[2]

In evidence of daily observations of the glass, we may quote the following story.

A favourite barometer owned by Bishop Hough, President of Magdalen until 1701, was once thrown down on to the floor by some clumsy young curate. 'Don't be uneasy, sir,' said

[1] Wren, *Parentalia* 217.

[2] *Phil. Trans.*, Apr. 2, 1666.

the Bishop, 'I have observed this glass daily for upwards of seventy years, but I never saw it so low before.' He died in 1743, aged 93. If the story be true, his instrument would have dated from 1673, when he took his B.A. degree.

In 1678 members of the Royal Society experimented with the barometer on the Monument, and in July 1682 CASWELL of Hart Hall was one of the first to observe the mercury standing at $25\frac{6}{10}$ inches on the top of Snowdon. A barometer was purchased for the Common Room of Magdalen College in 1688 for $1^{li}\ 15^{s}$.

187. Barometer with bent tube. **? 1750.**

Clarendon Lab.

Mounted by the side of a looking-glass.

To Sir SAMUEL MORLAND (1625–96) of Winchester and Magdalene College, Cambridge, Master of Mechanics to the King, is attributed the invention of the barometer with an inclined tube.

The idea of a bent barometer tube was communicated by a friend to WM. DERHAM, and by him to the Royal Society in January 1698. It is described in his explanation as serving 'for the more nice measuring the height of the Mercury. For an inch of perpendicular height may be made 2 or 3, by bending the Tube more or less.'[1]

Sometimes the mercury had a tendency to stick, but Orme of Ashby-de-la-Zouch in Leicestershire had a particular way of preparing the mercury which was said to be efficacious in preventing this.

Barometer with bent tube. 1753.

By F. Watkins, London.

The property of Capt. Spencer Churchill, Northwick Park. The diagonal portion of the tube is graduated for readings between 28 inches and 31 inches. The scale is divided into $\frac{1}{100}$ inch parts, and is lettered

Stormy—$\frac{\text{Much Rain}}{\text{Much Snow}}$—Rain—Changeable

Changeable—Fair—$\frac{\text{Set Fair}}{\text{Set Frost}}$—Very Dry.

The rectangular frame, supporting the barometer,

[1] Wm. Derham, *Letter on Experiments on the height of Mercury in a Barometer, Phil. Trans.*, Jan. 1698.

hygrometer and a thermometer, and measuring about 2 feet × 3 feet, encloses *A Perpetual Regulation of Time*, published by permission of the Company of Stationers. The dials of this calendar are worked by seven cog-wheels at the back of the frame.

A similar instrument made by T. Whitehurst of Derby, 1772, used to be in the Peel Park Museum at Salford.

189. Barometer. **In use 1774–1838.**
In the Quadrant Room, Radcliffe Observatory.

By J. Bird.

190. Barometer.
In Senior Common Room of Christ Church.

191. Barometer.
Radcliffe Observatory.

By Thomas Jones, 24 Charing Cross.

192. Barometer.
Queen's College.

By Nairne and Blunt, London.
With a small tube $\frac{1}{10}$ in. diam.

Barometer. **Before 1776.**
Royal Society.

By Ramsden. *Phil. Trans.*, vol. 66, p. 383.

Barometer. **c. 1820.**
Royal Society.

By Newman, under direction of Mr. Daniell, *Meteorolog. Essays*.

Barometer. **1824.**
Royal Society.

By Newman, under direction of Sir H. Davy, with iron plunging cylinder compensating for difference of capacities.

Water barometer.
Royal Society.

By Newman, under direction of Mr. Daniell.

Differential barometer. **1829.**
Royal Society.

By Dr. Wollaston. *Phil. Trans.* 1829, p. 133.

193. Marine Barometer.

University Observatory.

By Negretti and Zambra, 1 Hatton Garden and Cornhill, London.

194. Barometer. **Before 1860.**

University Museum.

By Newman, 122 Regent St., London.

Facsimile of the Standard Barometer at the Royal Society, constructed for the late Dr. Wm. Prout, F.R.S. Presented by the Rev. J. I. Prout, M.A., Student of Christ Church 1860.

195. Barometer. **18—.**

University Museum.

Single tube, graduated on the glass.

A new **Baroscope** was described by John Caswell, Professor of Astronomy, in the *Philosophical Transactions*, xxiv, p. 1597, in 1704.

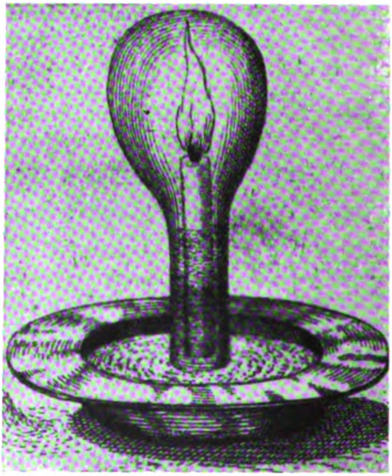
Names of other makers noted on Oxford barometers are Gally & Co, London; Manticher fecit; W. & S. Jones, Holborn; Salmon, Oxford: but their work is not dated.

THE STUDY OF GASES

'On Monday, the 14th of September 1818, the foundation-stone of the buildings for making gas, for the purpose of lighting the University and City, was laid by four Gentlemen of the Gas Light Committee. These buildings are erected on the banks of the Isis, in a ground near Littlegate, called the Friars, from its formerly being the site of a Monastery of the Franciscans or Grey Friars. On the 6th of September 1819, the brilliant and pure illumination with gas became general throughout the University and City.' *The Oxford Guide*, 1825.

The early experimentalists collected their gases in glass vessels and in distensible bladders. In the first part of this volume it is stated that Mayow of All Souls College was the first chemist to collect gases over water, or in a particular case over oil of vitriol, in 1674, and to have studied change in volume in the gas by observing the rise and fall of water in the glass vessel (p. 33). I have now discovered that Mayow was anticipated in his employment of the pneumatic-trough method, by another Oxford man, who had published his ex-

periments more than fifty years earlier. ROBERT FLUDD of St. John's and Christ Church described, with a picture, the classic experiment of a candle burning in a small volume of air standing over water, and it may have been this very illustration which suggested a similar procedure to Mayow. In any case Fludd was no chemist, and Mayow can hardly receive the entire credit for the invention of the pneumatic trough.



FLUDD'S EXPERIMENT, 1617.
De Macrocosmi Historia, p. 471.

Stephen Hales (1727) separated the receiver from the generator of the gas, and is considered by Dr. Lowry[1] to have the credit of priority in this invention. Sir CHRISTOPHER WREN had, however, achieved a similar result in a rather different manner sixty years earlier. About 1664 he 'suggested to put a fermenting liquor in a glass ball, and to fit a stop cock to it, and ty a bladder about the top of the stop cock, by which means the Air, to be generated by the fermenting liquor, would pass into the bladder, and upon turning the stop cock be kept there in the form of Air'.[2]

[1] *Historical Introduction to Chemistry*, 1915, p. 84.
[2] *Phil. Trans.*, Nov. 22, 1675, p. 445.

ROBERT BOYLE AND HIS CYLINDER

From Tilden's 'Famous Chemists'

AIR-PUMP

Few inventions were more opportune than that of the air-pump by Otto von Guericke of Magdeburg (1602–86) in 1654. Stimulated by this contrivance for exhausting air from a vessel, ROBERT BOYLE (1627–91), aided by HOOKE, invented the **Machina Boyliana** (*c.* 1658),[1] which has already been figured on page 16. With this instrument he performed his classical experiments on the weight, the pressure, and the elasticity of the air, and in the part it plays in respiration and in acoustics. And as the result he formulated the Law which is now associated with his name, that the pressure exercised by a given quantity of gas is proportional to its density.[2]

An early reference to the air-pump occurs in the Minutes of the meeting of the Royal Society for 2 January, 1660–1, when Mr. Boyle was requested to bring in his 'cylinder', and to show at his best convenience his experiment of the air. On 13 February the Danish Minister was 'entertained with experiments' on the air-pump. Improvements followed, but apparently not as rapidly as the Society desired, for on 27 March Mr. Boyle was 'desired to hasten his intended alteration of his air-pump'. Whether or not he effected the alteration, we do not know; but on 15 May he absolved himself of further responsibility by presenting the Society with his engine, which afterwards became a central attraction at their gatherings. On 12 February, 1661–2, Dr. Wren proposed to try a watch in Mr. Boyle's engine, and it was possible that the discovery that sound requires a material medium for its transmission was then made.

Boyle's '*Aire-Pump*; or an Engine to exhaust the Air out of any vessel fitly applied' was certainly in the Cabinet of the Royal Society in 1681,[3] and is popularly believed to be there still, but the two-barrelled Air-pump that has been passed off as his, is most certainly an air-pump 'according to Mr. Hawksbee's best and last Improvements', several of which were made by members of the craft of Pneumatical Instrument-Makers early in the eighteenth century.

[1] Boyle, *New Experiments, Physico-Mechanical, touching the Spring of the Air and its Effects*, 1660.

[2] The Law was rediscovered, it is said independently, by Marriotte in France fourteen years after Boyle.

[3] Grew, *Catalogue of Rarities.*

Standing Air-Pump with double barrel. c. 1710.
No. 49, Royal Society.

By F. Hawksbee, or one of his imitators.

Such pumps, with much accessory apparatus, were made and sold 'by *Richard Bridger* (who was Apprentice to the late *Mr. Hawksbee, F.R.S.*) at the upper end of *Hind-Court,* Fleetstreet; and *William Vream* Pneumatical Instrument-Maker, at his House in *Earl-street* near the *Seven Dials* within two Doors of the *Royal Oak*'.[1]

And even as late as 1766 this 'elegant and magnificent Form' was in use for those who would go to the price of it.[2]

Among the eighteenth-century makers of Air-pumps we have noted the names of W. VREAM, *c.* 1717; THOMAS RIBRIGHT, 1749; and RICHARD BRIDGER.

Air Condenser.
No. 51, Royal Society.

By Nairne.

Perhaps the 'Great CONDENSING ENGINE of Brass, contrived to ram and crowd a great quantity of Air into a little room. Whereto is also fitted an Iron Gun or Barrel.' But it might also have been the 'Little Condensing Engine of Glass, with a brass-neck, Rammer and Valve fitted to it'; both of which were in existence in 1681.

196. **Air-pump with double barrel**, and box of apparatus. 17—.
Oriel College

Table form, contrived by Davenport.

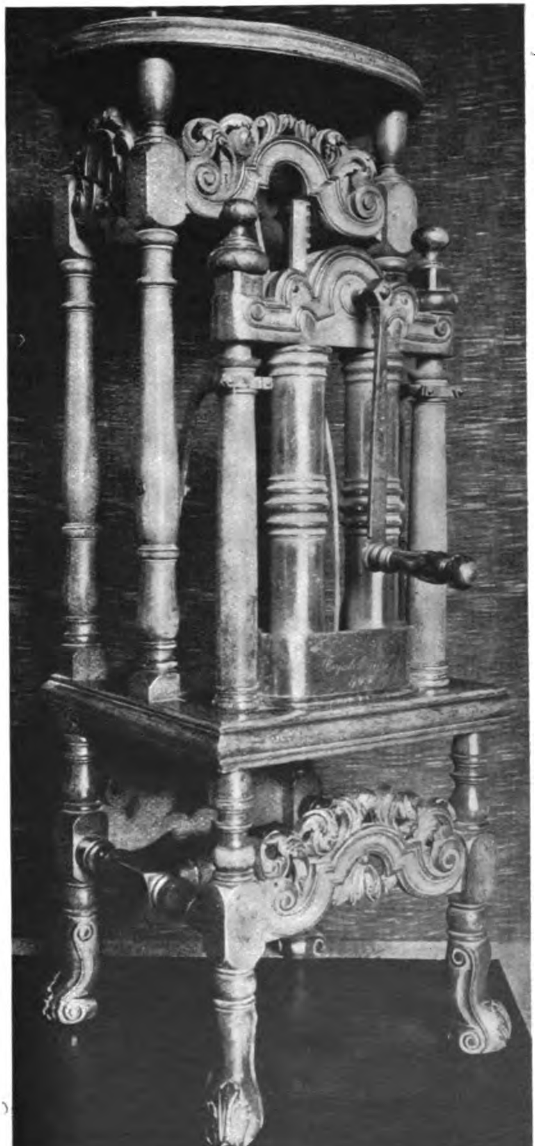
Made by *Edward Nairne, London.*

Barrels 8 in. × $1\frac{1}{4}$ in. $4\frac{1}{2}$ inch stroke.

Sundry apparatus for ditto; Glass Receivers; Guinea and feather apparatus; Bladder in bottle to show expansion; Bell to ring in vacuo; 3-inch Magdeburg Hemispheres.

197. **Condensing Syringe and Copper Globe,** $7\frac{1}{2}$ in. diameter.
Oriel College.

[1] W. Vream, *Description of the Air-pump*, London, 1717.
[2] B. Martin, *Description of a new Air-Pump*, 1766.



HAWKSBEE'S AIR PUMP

Royal Society

SOUND

'Time is. Time was. Time is past.'
R. Bacon's Speaking Head.

ONE of the first works of importance on Sound by an Oxford man was the *De Templo Musicae*, published in 1617 as part ii of the second volume *de Macrocosmi* of ROBERT FLUDD. The relations of musical intervals are set out at length, and various musical instruments are figured and described, ending with an Instrumentum Magnum, or mechanical harp, invented by the author and mechanically driven by a Worm-Jack. Fludd recognized that Sound was a result of the movement and collision of air.

The early experimentalists who studied the problems of the reflection of sound were generally dependent on chance local conditions. The face of nature or the disposition of buildings supplied them with all the apparatus they needed. The **echoes** of the vicinity of Oxford were investigated with systematic care by ROBERT PLOT (1677), and were described by him.

'It will not be amiss', he wrote in his *Natural History of Oxfordshire*, 'to entertain the reader awhile with the Nymph Echo; a mistress she is indeed that is easily spoke with, yet known to few: if therefore I take pains to acquaint him with her, I hope I shall not perform a thankless office.

'First therefore, that Philechus may not be out in his choice, whenever he attempts to court her in Oxford-shire, he must know that of these there are several sorts, and may best, I suppose, be distinguish'd by their objects, which are,

either
- single, such as return the voice but once; and these again are either
  - polysyllabical, such as return many syllables, words, or a whole sentence.
  - tonical, such as return the voice but once, nor that neither, except adorned with some peculiar musical note.
- manifold, and these return syllables and words, the same oftentimes repeated, and may therefore be stiled tautological echo's, which are caused either by simple / double reflexion.

Polysyllabical articulate echo's

'The strongest and best I have met with here, is in the Park at Woodstock.

'In the day time, little wind being stirring, returns very distinctly seventeen syllables, and in the night twenty: I made experiment of it with these words,

—Quæ nec reticere loquenti,
Nec prior ipsa loqui didicit resonabilis Echo.

In the day it would return only the last verse, but in the night about twelve by the clock, I could also hear the last word of the former hemistick [loquenti.] The object of which echo, or the centrum phonocampticum, I take to be the hill with the trees on the summit of it, about half a mile distant from Woodstock town, in the way thence to the Right Honorable the Earl of Rochester's Lodge: and the true place of the speaker, or centrum phonicum, the opposite hill just without the gate at the towns end, about thirty paces directly below the corner of a wall inclosing some hay-ricks, near Chaucers house: some advantage I guess it receives from the rivulet that runs as it were in a direct line between the two centers, and from the pond at the foot of the object hill; as also from two other hills that run obliquely up to it: which may better be apprehended by the prospect of the place, as in tab. 1, fig. 2.

'That this echo makes return of so many syllables, and of a different number in the day and night, being indisputable and matter of fact; I proceed in the next place to the reasons of these certainties, which possibly to every body may not be so plain. First then, the causes why some echo's return more, and some fewer syllables, I take to lye in the different distances of the objects (returning the voices) from the places of the speakers: for by experience 'tis found, that if the speaker be too near the object, the return is made so quick upon him, that the echo is as it were drowned in the voice: but if he remove farther from it, then it begins to be clear and distinct; and if it be a polysyllabical one, it first repeats one syllable, then two, three, four, five, or more, according as the speaker removes farther off it, which I take to be the only true way of measuring the proportions of the spaces of the ground, requisite for the return of one or more syllables. That this is true, I shall use no arguments to perswade, because the experiment is subject to every mans tryal; and if so, it must necessarily be admitted, that the reason why this echo returns so much, is because of the great distance of the object from the speaker.

'I carefully examined this echo, and found, upon motion backward, forward, and to each hand, the true centrum phonicum, or place of the speaker, to be upon the hill at Woodstock towns end, about thirty paces below the corner of the wall aforesaid, directly down toward the Kings Majesties Manor: from whence by measure to the brow of the hill, on which my Lord Rochesters Lodge stands, are 456 geometrical paces, or 2280 feet; which upon allowance of 24 geometrical paces, or 120 feet to each syllable, to my great satisfaction I found to be agreeable to the return of 19 syllables, viz. one fewer than it returns in the night, and two more than in the day.

'The measure I must confess had been much more easie and natural, could I have began from the object, and so removed backward accordingly as the echo gradually increased in the repetition of more syllables; for then I could have given the due proportion to each, if I had found any inequality upon the increase, which I guess there may be, because the allowance of an equality seems to set the object too far off by a syllable or two. But it not being feasible in this place, I was forced to take the former course; for in the valley between the two hills, being the whole medium through which the voice passes, and the echo returns it, there is scarce any such thing as an echo to be found; nay, if you stand at the manor it self, which is not far from the true place of the speaker, and situate almost as high, and direct your voice toward the place of the object, you shall not have the least return; whence 'tis most evident that I could not use that procedure here, and therefore must desire to be held excused from giving the proportions of space, which I suppose, according to Kircher may decrease, according as the number of syllables increase, till I meet with an echo fit for the purpose.

'The reason of the difference between day and night, why it should return seventeen syllables in the one, and twenty in the other, may lie, I suppose, in the various qualities, and constitution of the medium in different seasons; the air being much more quiet, and stock'd with exhalations in the night than day, which somthing retarding the quick motion of the voice to the object, and its return to the speaker somwhat more, (by reason the voice must needs be weakned in the reflexion) must necessarily give space for the return of more syllables.

'Amongst other tryals of this echo, I discharged a pistol, which made a return much quicker then my voice, and (at which I still wonder) with a much different sound from that the pistol made, whence I can only conclude, that the more forcibly the air is stricken, (as also in the projection of a ball)

the sooner the response is made, and that possibly there may be some sounds more agreeable to every echo, than others. And it being my Lord Bacon's opinion, that there are some letters that an echo will hardly express, and particularly the letter S, which, saies he, being of an interior and hissing sound, the echo at Pont Charenton would not return; hereupon I tryed, as well as his lordship, with the word Satan, beside many others of the same initial, but found the echo here neither so modest or frighted, but that, though the devil has been busie enough hereabout (as shall further be shewn near the end of this history) it would readily enough make use of his name.

'**Polysyllabical Echo** in the water-walks, near the bull-work called Dover Peer at Magdalen College.

'It repeats a whole hexameter verse, but not so strongly as Woodstock: where the true object of this may be, cannot so well be found by measure, because of the many buildings interposing; but I conjecture it may be about the publick schools, or New College. I could gladly, I confess, have assigned it somthing further off, because I fear that distance falls somwhat short of our former account, but the buildings beyond lying all lower then those, it must by no means be admitted; which makes me think, there must be a latitude allowed in these matters, according to the different circumstances perhaps of time, as well as place; and that possibly Mersennus might not be so much mistaken, when he assigned to each syllable but 69 feet.

'**Tonical Echo's,** such as return but some one particular musical note, I have met with several, and do not doubt but they are to be met with in most arched buildings, though scarce observed or noted by any.

'Echo in the gate-house at Brasen-nose College answers to no note so clearly, as to gamut.

'The curious and well built gate of University College, to none so well as B mi.

'The like note I met with again at Merton College, in the vault between the old and new quadrangles.

'Ditto in the large arched vault of Queens College gate.

'The stately arched stair-case leading into Christ Church great hall, will return all the notes through the scale of musick.

'These I must confess are but echo's improperly so called, because they will express nothing that's articulate, and therefore rather fall under the notation of a bombus; yet their cause being somwhat nice and subtile, I thought not fit to pass them by, but to take occasion from hence to advertise

the reader, that there are some other inanimate bodies beside the load-stone, that though they have no sense, yet have a sort of perception, which I take to be sufficiently proved from these vaults, that seem to have a kind of election to embrace what is agreeable, and exclude all that is ingrate to them: thus are the very seats in churches and chappels affected with some peculiar notes of the organ; and I have a friend (a violist) whom I dare believe, that says, his thigh is thus sensible of a peculiar note, as oft as he lights on it during his playing. Some have imputed much of this in buildings, to the figure and accurate structure of the arch, and that where they have different shapes and magnitudes, there will be different tunings also: but I do not find it agreeable to experience, there being another vault in the entrance into Merton College chappel, much less, and of a far different figure from that other before mentioned in the same college, which returns very near, if not exactly the same note: and so do the gates of Queens and University Colleges, than which in height, breadth and length, there are few more different.

'It must therefore rather be referr'd to the pores of the stones, which are fitted to receive some vibrations of the air, rather than others; just as in two viols tuned to a unison, where the strings being screwed to the same tension, and their pores put into the same figure, if you strike one, the corresponding string of the other viol presently answers it: because the first string being of such a tension, and having pores of such a form, makes vibrations in the air, suitable only to the pores made by the same tension in the other string.

'**Tautological Polyphonous Echo's,** such as return a word or more, often repeated from divers objects by simple reflection, there are none here eminent; the best I have met with is at Ewelme, on the side of a bank, in a meddow south and by west (about a furlong) from the church: it returns the same word three times, from three several objects of divers distances, which I guess may be, 1. The Manor, 2. The Church and Hospital, and 3^d^. Colonel Martins house.

'Another there is near Oxford, about the east-end of Christ Church new walk, that repeats three or four syllables twice over.

'A treble one at the most northern point of the fortifications in New Parks.

'But there being many better than these of the kind no doubt in other places, I shall reserve their consideration at large to a better opportunity, and only take notice here by the

way, that these are never of many syllables; and that always, by how many more they are of, by so many the fewer times they repeat them, because so great distance will be required for their objects, that they must quickly be removed out of the reflex action of the voice: for suppose but a sentence of ten syllables, viz. Gemitu nemus omne remugit, and allow, as before, for the return of each syllable 120 feet, the first object must be 1200 feet off; and the second, with abatement for distance, at least 2000; and the third, certainly out of the voices reach, beyond all hopes of any response. Indeed, could we meet with one of Mersennus's echo's, where sixty nine feet would return us a syllable, then such an hemistick might be resounded three times, or perhaps a whole hexameter twice; yet however small a space may be found for the clear repetition of such a verse, I cannot think it can possibly be, that any echo should repeat one eight times over: for suppose a smaller distance would suffice, then that allowed by Mersennus, as but 350 yards to a verse of seventeen syllables, and allowing some decrease for the objects distances; yet I do not doubt, but two or three of the furthest must needs be out of the voices action.

'But though we have no considerable tautological echo's, by a simple reflection, yet we have others of no inferior account made by a **double** one, which also arising from divers objects, though in a different manner, belong to this place. Of these, though there are scarce any that will return a trissyllable, occasioned, I suppose, by the nearness of the secondary objects, yet a clap with the hands or stamp of the feet, there are some will return eight, nine, or ten times, the noise dying, as it were, and melting away by degrees with such a trembling noise, that I somtime thought of the epithet [tremulous] to discriminate this sort of echo from the rest.

'At Heddington, in the garden of one M^r^ Pawling mercer of Oxon: there is a wall of about 40 yards long, built for the advantage of the fruit, with divers niches; to which, if you stand but a little obliquely, so as to see the peers standing out between each two of them, you have the several objects of such an echo, not above nine or ten foot distant from each other, which return a clap with the hand, or a monosyllable (the wind being quiet and still) at least nine, if not ten or eleven times, but so thick and close, that even a dissyllable breeds a confusion: where by the way if it be objected, that (the whole wall being but 40 yards, or 120 foot long) according to the afore-limited distance for echo's, a monosyllable should not be returned above once at most: it is to be noted, that these echo's made by a double reflection, begin (quite contrary

to all others) at the remotest object from the corpus sonorum, which in as many as I have yet seen, is a distinct wall, falling on that; on which the rest of the objects are, in right angles; and this object it is, that first terminates the voice, clap, or stamp; and from which, by reflection, they next strike the ultimate secondary object, then the penultimate and antepenultimate; which, though nearer to the corpus sonorum in respect of the situation of the objects, yet are still further off in respect of the voice, or other sounds motion: whence it comes to pass, that the nearest object to the corpus sonorum is last stricken, and therefore repeats a syllable as well as any of the rest, because indeed in that respect the furthest from it.

'After the voice or clap has stricken these secondary objects, by way of accession as it were to the corpus sonorum, it is carryed again by a second reflection away from it toward the primary object, and somtimes over it, as it appears to be in this echo at Heddington, where the sound seems as it were somwhat refracted, for it is heard quite out of the place, as is evident to any one that stands in the north-east corner of the garden and speaks westwards, who will hear the echo rather in the hortyard on the other side the wall, than in the garden, which I take most certainly to be occasioned by this second reflection; for let any one that suspects the echo to be really in the hortyard, and not in the garden, go but into it, and he shall there find no such matter as an echo. All which, is more fully explained in tab. 1. fig. 4. where

a. is the place of the speaker or maker of any other sound.

b. the primary object first terminating the sound, and reflecting it on the peers of the other wall.

cccccc. the peers between every two niches that receive the sound reflected from the primary object and make the echo.

dddddd. the lines wherein the voice is carryed back again over the primary object, whereby the echo appears out of its place.

But herein let it be noted, that I am not so sanguine as to exclude all fears that it may be otherwise, but only suggest what seems most probable at present, cum animo revocandi, whenever I shall be better informed by another, or my own future experience.

'At New College in the cloysters, there are others of this kind, to be heard indeed on all sides, but best on the south and west, because on those there are no doors either to interrupt or wast the sound: these return a stamp or voice, seven,

eight, or nine times, which so plainly is occasion'd by the peers between the windows, that on the west and shorter side (being but 38 yards long) the returns are more quick and thicker by much than on the south, where the primary object being above fifty yards removed from the corpus sonorum, and the secondary ones proportionably further; the returns are much slower and more distinct, in so much that on that side the echo will return a dissyllable, whereas on the west side you can have but a monosyllable only. If it be objected, that according to the rule, 38 yards are not enough for the return of a monosyllable; I answer, that though it may be likely enough that the return of the primary object on that side is not heard, yet that there is none of the secondary ones, or peers between the windows, but what are distant from the speaker above 40 yards, and therefore may well return a monosyllable. And if again it be objected, that the interval of an echo must be liberum and patens, and it be further demanded how it comes about that we have such echo's in cloysters, when we can have none in wells that are cover'd with houses, because the interval is closed at both ends, as this cloyster is: it must be answered, that the rule holds only in narrow intervals closed up on all sides, and not in such cloysters that are open and arched to the top.

'Which may also be the reason why at Magdalen College, where the cloysters are covered with a flat roof, they have but an inconsiderable echo, and at Corpus Christi none at all; notwithstanding they have all other conditions requisite.

'In the cloyster at All-souls College, in the north and west sides, where no doors hinder, there is much such another, which to the stamp of ones foot, or clap with the hands, answers four or five times, with a noise not unlike the shaking of a door, and in nothing differing from the former, but that to the voice it makes no response: and indeed, it would be matter of wonder if it should, since no one side of that cloyster comes near the distance assigned for the return of a syllable, whereas that at Heddington just equals it, and one side of New College much exceeds it.

'Other echo's there be that belong to this place, as echo's upon echo's, and such as my Lord Verulam stiles back-echo's; of which, because I have met with none considerable, I am content to pass them by, having sufficiently, as I suppose, by this time tired the readers patience with too tedious a consideration of so particular a subject.'

ROBERT HOOKE ascertained the number of vibrations corresponding to musical notes in July 1664, and thus

told 'how many strokes a fly makes with her wings'. Pepys, *Diary*, iv. 43. He invented the 'otocousticon',[1] an aid to hearing, and anticipated some of Chladni's work on nodal lines on vibrating surfaces. Of even greater importance were his experiments for finding the **velocity of sounds** with small and great guns, with and against the wind, in August and September 1664. In these experiments Dr. Charleton took part. 'Divers musical experiments' were tried at Oxford during the summer of 1665, which were reported on by Dr. Wallis at the Royal Society's meeting on 14 March, 1665-6.

The **Resonance of Strings** was first shown to Plot by the ingenious THOMAS PIGOT, B.A., F.R.S., and Fellow of Wadham College in 1677, some two years after the phenomenon had been observed by WILLIAM NOBLE, M.A., of Merton (matric. 1667, died 1681), and their observations were communicated by J. Wallis to Boyle in a letter dated 14 March, 1676-7. A careful investigation of the phenomenon was made by the Rev. Narcissus Marshe, D.D.,[2] Principal of St. Alban Hall (1673-8), whose conclusions are printed in extenso by Plot, pp. 289-99.

Plot's account of the discovery is as follows:

'It hath been lately observed here at Oxford, that though viol or lute strings rightly tuned do affect one another, yet most of them do it not in all places alike, as has till now been supposed: for if the lesser of two octaves be touched with the hand or bow, each half of the greater will answer it, but will stand still in the middle; and if the greater of the two octaves be touched on either of its halves, all the lesser will answer it, but if touched on the middle, the lesser will not stir any where at all. So if the lesser string of two fifths be touched on either of its halves, each third part of the greater will answer it, but if on the middle they will not stir; and if the greater of two fifths be touched on either of its thirds, each half of the lesser will answer it, but if in the divisions they will not stir: and so of twelfths, fifteenths, &c.'

[1] An 'otocoustick' of ivory was given to the Royal Society by Bishop Wilkins. They were also made of copper and of tin.

[2] Dr. Marshe had been a Fellow of Exeter College 1658-73, and afterwards became Provost of Trinity College, Dublin, 1678, and Archbishop of Cashel, Dublin and Armagh (1702) until his death in 1713.

In an *Essay touching the Sympathy between Lute or Viol Strings*, Dr. MARSHE

'first lays it down as a postulatum, that if two lute or viol strings be rightly tuned, the one being touched with the hand or bow, the other will answer, or tremble at its motion, which holds also in some measure in wire strings; and between organ pipes and viol strings, but not between wire and viol strings. For the clearer solution of which phænomenon in all its cases, he has laid down these two following principles.

Princip. 1. That strings which are unisons are of the same, or a proportionable length, bigness, and tension; so that by how much any string is longer than other, cæteris paribus, by so much smaller, or more tended; and by how much bigger, by so much shorter or more tended must it be, to render them unisons, wch will appear in the following cases. Whereunto he premiseth,

That in strings moved by an equal force, through a like medium, the difference of motion does arise from the difference of magnitude and tension, wherefore (the force and medium being alike) he

Premiseth 1. That strings of the same cize move equally fast, because they cut the air with the same facility. Hence

2. That the greater any string is in diameter (or circumference) the slower it moves (and on the contrary) because it finds the greater resistance in the air.

3. That strings of the same length and tension move to same distance, because they have the same compass to play. Hence

4. That the longer, or less tended, any string is, the farther it moves (and on the contrary) because of the greater compass it can fetch.

Whence he infers this conclusion,

That (in strings moved through the same medium) the swiftness of motion does arise from the greater force, and less cize or bigness; the compass of vibration, from the greater length (or force) and less tension; and the quickness or frequency of vibration, from the greater or swifter motion, and less compass.'

In the course of his lengthy and somewhat tedious investigation he made use of the method of testing for nodes and antenodes with paper riders. To ascertain whether a string is resonating or 'trembling', as he

has it, to another which has been touched with the hand or bow, he wrapped loosely narrow strips of paper round the string, and observed them 'dance and play up and down and about the string'.

Nor were their experiments confined to vibrating strings.

'One Hooper here of Oxford' was chosen as a *corpus vile* because he 'could so close his lips, as to sing an octave at the same time'. Plot knew of 'two other persons now living here, that can do it though their lips seem not to be set in that posture, yet they shut them so close that they can by no means pronounce any thing articulate. But he that excels them all, and indeed to a miracle, is one Mr. Joshuah Dring, a young gentleman of Hart-hall, who sings a song articulatly, ore patulo, and all in octaves so very strongly, & yet without much straining, that he equals if not excels the loudest organ. By what means he performs this, is hard to guess.'[1]

[1] Plot, *Nat. Hist. of Oxfordshire*, p. 299.

HEAT

Heat is 'a property of a body arising from the motion or agitation of its parts'. HOOKE, *Micrographia*, 1665, p. 37.

Heat is the result of a brisk molecular agitation. BOYLE, *Works*, i. 282.

HOOKE and BOYLE thus made a contribution to the theory of Heat, that has been widely attributed to Count Rumford, *c.* 1790.

Under the heading 'Heat' we can only deplore the absence of all really old apparatus in Oxford. It has gone the way of all flesh.

For the first efforts in scientific thermometry, as in so many other branches of Physics, we go back to Galileo who invented a thermoscope, though of an imperfect nature, about 1592.

Of ROBERT BOYLE it has been truly said that his researches were coextensive with the whole range of experimental investigation. 'To him we owe the secrets of fire, air, water.'[1] His classic researches on Heat were mostly published in his *New Experiments and Observations touching Cold, or an Experimental History of Cold begun. To which are added An Examen of Antiperistasis, and an Examen of Mr. Hobbes's* Doctrine about Cold. *Whereunto is annexed an* Account of Freezing, *brought into the Royal Society by the learned Dr. C. Merret, a Fellow of it.* The first edition of this *History of Cold*, written in 1662, was destroyed in the Great Fire of London. Boyle described the behaviour of open and closed Weather-glasses or Thermoscopes, of which he gives an engraving: indeed he is accredited with having been the first man in England to order the construction of hermetically sealed thermometers. His other experimental work included the measurement of the expansive force of freezing water, and observations on the effect of atmospheric pressure on ebullition. Of special importance too were his discoveries of 'infrigidating mixtures with sal armoniac and salt', and of their use both for

[1] Boerhaave, *Methodus discendi*, p. 152.

physical experiments, and the adjustment of weather glasses, and for the production of cool drinks and other such refreshments 'potently cooled', which may enable you to gratify not only the curious among your friends, 'but those of the delicate, that are content to purchase a coolness of drinks at a somewhat chargeable rate'.[1]

An important contribution to the knowledge of the conduction of heat and of the economic application of non-conductors, was due to a member of Balliol College, JOHN EVELYN, who communicated to Boyle a description of snow-pits or 'conservatories, wherein snow and ice are kept all the summer long' in Italy.[2] It will doubtless be found that the practice of building ice-houses in the grounds of English country houses dates from this time.

A very familiar experiment on expansion interested the Royal Society in 1664. On March 30, Hooke was ordered to make 'the experiment to prove that glass will stretch'. A bolt-head with a long small stem was filled with cold water and then put into warm water; whereupon it sank to half an inch whereas otherwise it rises by warmth. The cause of this sinking was by some ascribed to the stretching of the glass by warmth.[3]

WREN'S Thermometer was designed to obviate a source of error that he had noticed in the use of the ordinary air thermometers of the period. He found that the enclosed air, by reason of the weight of the liquor as it stood higher or lower in the glass, showed a contraction or extension, beside what is produced by heat or cold; he therefore 'invented a Circular thermometer, in which the liquor occasions no fallacy, but remains continually in one height, moving the whole instrument like a wheel on its axis'.[4] (*See* vol. ii, p. 389.)

To Wren's credit were also Thermostats for various uses, such as the Registers of Chemical Furnaces for keeping a constant heat.

The fixing of the thermometric zero at the freezing-point of water is stated to be due to the practical mind of ROBERT HOOKE, *c.* 1665.

[1] Boyle, *A New Frigorifick Experiment*, *Phil. Trans.* July 18, 1666, No. xv. [2] Boyle, *History of Cold*, Tit. xvi, Appendix.
[3] *Original Register*, iii, p. 23. [4] Sprat, *Hist. Royal Soc.*

Thermometers

Primitive Instruments

198. 'Oven Clock'.

Pitt Rivers Museum.

A quartz boulder fixed in the brickwork of an old oven near Chelmsford to indicate when the oven was hot enough for baking bread.

199. 'Dick' stone. 1901.

Pitt Rivers Museum.

From oven of old cottage near Bicester.

200. 'Dick' stone. 1912.

Pitt Rivers Museum.

From oven of old cottage near Stanton Harcourt, 1912.

Modern Instruments

201. Thermometer graduated 100° to 0°. ? 1750.

Clarendon Laboratory.

Mounted on the right-hand side of a looking-glass as a pendant to a diagonal barometer.

202. Six's Maximum and Minimum Thermometer. 1782.

Daubeny coll., Magdalen Laboratory.

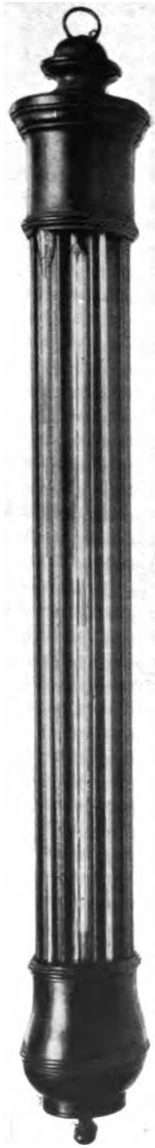
This fine instrument is the only one of its kind known to us. It corresponds in every detail with the original described in James Six's *Account of an improved Thermometer* in the *Phil. Trans.* lxxii, plate 3. It is 2 ft. 2 in. in length, and is probably the oldest of this important type of thermometer now in existence.

203. Six's Maximum and Minimum Thermometer. 1828.

Radcliffe Observatory.

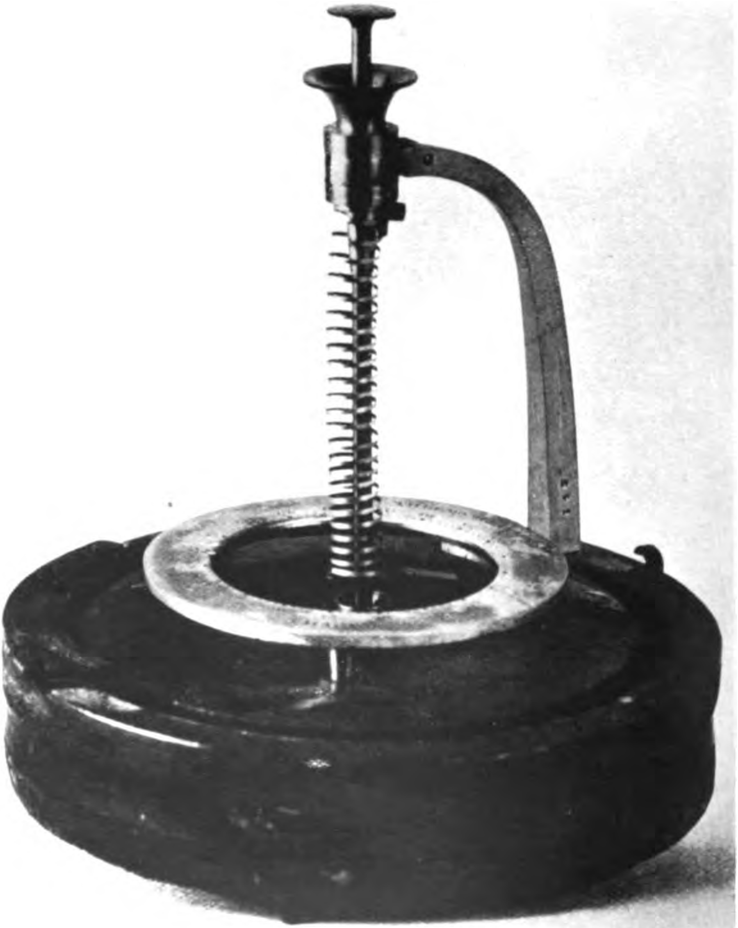
By Troughton.

Purchased for £2 12*s.* 6*d.*



ORIGINAL SIX'S MAXIMUM AND MINIMUM THERMOMETER

Daubeny Laboratory, Magdalen College



NO. 205. BRÉGUET'S THERMOMETER, C. 1800

Daubeny Laboratory, Magdalen College

Six's Maximum and Minimum Thermometer.

Royal Society.

By W. Cary.

Boxwood scale 12 inches long. Range: 5° to 125° F.

204. Hicks' Mercurial Maximum and Minimum Thermometer. 18—.

University Museum.

By 'Casella London Sole Maker'.

205. Bréguet's Thermometer. c. 1800.

Magdalen Laboratory.

By A. L. Bréguet of Paris.

Bequeathed by Dr. Daubeny, and used until 1920 for demonstrating the effect of the expansion of dissimilar metals by heat.

206. Wet and Dry Bulb Thermometer.

University Observatory.

By Bennett, Watchmaker, Cheapside.

Mercury Thermometers by the following makers were in the possession of the Royal Society in 1834:

		Length.	Range.	
Dollond	Brass scale	23½ in.	−20° to 535°	Fahr.
Troughton & Simms	Scale	15 „	0° „ 215°	„
Crichton	Ivory „	7½ „	32° „ 105°	„
Pres. by Dr. Ure, F.R.S.				
Bird	Boxwood scale	10¾ „	−15° „ 230°	„
„	„ „	9¾ „	−20° „ 225°	„
„	„ „	11 „	−40° „ 250°	„
Nairne	Lancewood „	17½ „	−7° „ 212°	„
Newman	Ivory „	6½ „	−3° „ 120°	„

Spirit Thermometer. 1827.

By Newman, for very low temperatures. Employed by Captain Foster at Port Bowen. *Phil. Trans.* 1827, p. 125.

According to Boyle, the first sealed spirit thermometers came from Italy. (Meeting of Royal Soc., Oct. 14, 1663.) They were made by Ferdinand II, Duke of Tuscany, *c.* 1641. It is possible that the old Macclesfield instruments, *c.* 1740, may still exist at Shirburn, but our inquiries have failed to elicit any satisfactory reply.

OPTICS

LENSES

Burning Glasses

The use of lenses for making fire was of great antiquity in the Eastern Mediterranean. A passage in the *Clouds* of Aristophanes, Act 2, which was performed in 424 B.C., makes distinct reference to burning glasses. Strepsiades remarks to Socrates that he has no doubt seen in the hands of the druggists the fine transparent stone with which they light the fire. Socrates asks him if it is glass that he speaks of, and Strepsiades, replying in the affirmative, adds that by holding this stone to the fire, he could, at a distance, melt any writing of assignation (such writings were traced on wax), and thus free himself from his debts.

A perfect plano-convex lens of rock crystal was found by Layard in excavations at Nimroud.

In our own country the practice of kindling the new fire on Easter Even by a burning glass was not uncommon in the Middle Ages. An entry to that effect occurs in the Inventory of the Vestry, Westminster Abbey, in 1388.

'Unus lapis de berillo rotundus pro novo igne in vigilia Pasche a sole capiendo.'

So too at York, 'ignis de berillo vel de silice exceptus'.[1]

Large burning glasses were greatly treasured by the early scientists, who occasionally mention them in their wills. Sir Kenelm Digby, for instance, left his burning glass to the Earl of Bristol in 1665. Dr. Wilkins of Wadham College presented two to the Royal Society in November 1663. One was in a brass, the other in a wooden, frame.

We have a fine example of the philosopher's burning glass in Oxford.

[1] *Surtees Soc.*, 1874, i, p. 109.

207. Large Burning Glass. **18th cent.**

See p. 75. Chemical Department.

There is nothing to show who was the maker of this large lens, but it undoubtedly dates from the days of the old Ashmolean Laboratory.

Such burning glasses—12 and 16 inches in diameter—were used by Joseph Priestley, *c.* 1770, who obtained them from Samuel Parker (*d.* 1817), a London optician.

Refraction of Light

With a convex lens any child would speedily discover the chief properties of a magnifying glass.

That a bottle or glass full of water will make small letters appear larger was known to Seneca (A.D. 12–65), and that a glass globe of water 'held to the sun could light a fire even in the coldest weather' is mentioned by Lactantius A.D. 303, and was probably common knowledge long before that time.

The early writers on Optics confine their attention to reflection by mirrors, and to simple refraction; they do not say much about lenses.

Euclid, 300 B.C., proved the equality of the angles of incidence and refraction, and has interesting observations on convex and concave mirrors. Seneca descants on the colours of the prism and on the magnifying power of concave mirrors.

Cleomedes (A.D. 50) noted phenomena of refraction, which were treated by Ptolemy in the most masterly manner in his *Liber de opticis sive aspectibus*. Here he records the angles of refraction from air to glass, which he ingeniously measured by using a semi-cylinder of pure glass. His theory of astronomical refraction was more complete than that of any astronomer before the time of Cassini.

Among the Arabs, Ebn Haithem (A.D. 1000) is said to have produced a work which treated of direct reflected and refracted vision, and also of living mirrors. This work has been unfortunately lost, but Bacon's contemporary J. Peckham is said to have been acquainted with a translation of it. The only optical work that has reached our times is the Treatise on Optics by Alhazen (A.D. 1100). Apparently quite an original work, com-

posed without reference to Ptolemy, the Arabian physicist proved that the rays which produce vision come from the object to the eye. He gives an anatomical description of the eye, explaining the share which each of its parts has in vision. He described seven kinds of mirrors, and has the sole merit of determining in general the focus of reflected rays, when the place of the eye and that of the object are known.

In 1270 VITELLO, a Pole, wrote a comprehensive work on optics which appears to have been based upon the work of Alhazen. He remeasured the refraction of air and water, and air and glass, with greater accuracy than Ptolemy had done. He discussed the foci of spheres of glass and the apparent sizes of objects seen through them, although he was not successful in putting the focus in the right place, in spite of the fact that he demonstrated the possibility of firing bodies placed beyond the sphere by the transmitted rays of the sun.

About ten years after Vitello, JOHN PECKHAM or PISANUS, *c.* 1240–92, Archbishop of Canterbury, published his *Perspectiva communis*, which went through many editions, though it contained nothing that was either very new or very important.

Such was the state of optical knowledge when ROGER BACON returned from his travels and proved to posterity how fruitful was his 'Ratio inveniendi'. In the *Opus majus* dedicated to Clement IV, *c.* 1265, he sketched out the properties of convex lenses in a more masterly way than any of his predecessors.

'If the letters of a book, or any minute object, be viewed through a lesser segment of a sphere of glass or crystal, whose plane base is laid upon them, they will appear to be far better and larger. Because by the fifth canon about a spherical medium whose convexity is towards the eye, and the object is placed below it, and between the convexity and its centre, all things concur to magnify it. For the angle under which it is seen is greater, and its image is also greater and nearer to the eye than the object itself, because the object is between the centre and the eye; and therefore this instrument is useful to old men, and to those that have weak eyes; for they may see the smallest letters sufficiently magnified.

'But if the medium be the larger segment of a sphere, or but half of one, then by the sixth canon, the apparent visual

angle will be greater than the true, and the image also greater than the object; but the place of it will be beyond the object, because the centre of the sphere is between the eye and the object; and, therefore, this instrument is not so powerful in magnifying as a lesser segment of a sphere.

'Also instruments made of crystal bodies, with plane surfaces, by the first canon about planes, and with concave surfaces, by the first and second canons about spherical surfaces, will perform the same thing. But the lesser of two segments of a sphere magnifies more manifestly than any of them all, by reason of the concurrence of all the three causes, as I said before.'[1]

The passage from which the principle of the telescope is believed to have been known to Roger Bacon is as follows:

'Greater things than these may be performed by refracted vision. For it is easy to understand by the canons above mentioned, that the greatest things may appear exceeding small, and on the contrary; also that the most remote objects may appear just at hand, and on the contrary. For we can give such figures to transparent bodies, and dispose them in such order with respect to the eye and the objects, that the rays shall be refracted and bent towards any place we please; so that we shall see the object near at hand, or at a distance, under any angle we please. And thus from an incredible distance we may read the smallest letters, and may number the smallest particles of dust and sand, by reason of the greatness of the angle under which we may see them; and on the contrary, we may not be able to see the greatest bodies just by us, by reason of the smallness of the angles under which they may appear; for distance does not affect this kind of vision, excepting by accident, but the quantity of the angle. And thus a boy may appear to be a giant, and a man as big as a mountain, for as much as we may see the man under as great an angle as the mountain, and as near as we please; and thus a small army may appear a very great one; and, though very far off, yet very near us, and on the contrary. Thus also the sun, moon and stars, may be made to descend hither in appearance, and to appear over the heads of our enemies; and many things of the like sort, which would astonish unskilful persons.'[2]

In these passages Bacon speaks with all the conviction of actual trial. In any case he was the first person to publish his belief that small objects could be magnified,

[1] Bacon, *Opus majus*, edit. Jebb, p. 352. [2] Bacon, *l. c.*, p. 357.

and distant objects brought near by means of single lenses and combinations of lenses, and that these effects were produced by enlarging by means of refraction the visual angles under which these objects were seen. We must, therefore, agree with the conclusion that Bacon magnified objects with his lesser sphere, or a convex lens. When we consider that a single lens or a single concave mirror, held at a distance from the eye, constitutes in reality a telescope, we can scarcely doubt that Bacon invented at least a telescope of this description.

The surpassing merit of the works of Roger Bacon was first publicly recognized in modern times at a meeting of the Royal Society on 20 March, 1678/9.

There is no reason to doubt, as some have done, the use of lenses in the thirteenth century. Spectacles were certainly in use in Italy. ALEXANDER SPINA of Pisa, who died in 1313, and who happened to see a pair of spectacles in the possession of another person, immediately constructed a pair for himself; moreover the tomb of Salvinus Armatus, a nobleman of Florence, who died in 1317, bore an inscription to the effect that he was the inventor of spectacles.

These records indicate that there was every probability that Bacon became acquainted with the manufacture and properties of lenses during his visit to Italy or even to Paris—and there is even direct testimony to the reality of Bacon's practical acquaintance with lenses. That he actually made lenses on his return to Oxford,[1] and it is extremely probable that he himself gave advanced instruction in this kind of learning, we gather from his own statement, 'the science of optics has not hitherto been lectured on at Paris or elsewhere among the Latins, save twice at Oxford'. The fame of Roger Bacon's lenses and mirrors lasted for centuries and his writings were a source of inspiration to several Oxford men, one of whom must be regarded as the first contriver of a telescope. *See* vol. ii, p. 289.

Descartes[2] is stated to have been the first of the

[1] 'Great talke there is of a glasse he ("Frier Bakon") made at Oxford, in which men might see things that weare don, and that was iudged to be don by power of evill spirites. But I know the reason of it to be good and naturall, and to be wrought by geometry, (with perspective as a part of it,) and to stand as well with reason as to see your face in a common glass.' R. Recorde, *Pathway to Knowledge*, 1551.

[2] *Dioptrique*, 1637.

moderns to publish figures and descriptions of machines for grinding and polishing lenses.

Spectacles

But how many centuries must pass before the benefits of even the simplest applications of a great invention are fully and generally realized! To-day lenses are more used to assist defective vision than for any other purpose. Yet burning glasses had been in use for a thousand years and more, before the greater utility of lenses of flatter curvature was discovered.

Aubrey was told by Dr. Pell that 'the antiquity of spectacles is of about 200 years standing, and that they were sold when first invented for 3 or 5 *li* a paire. The ancientest author wherin he finds them is cardinal Cusa.'

'The Germans call them Brill, from the beril-stones, i.e., chrystall, of which they were first made.' (Aubrey, *Lives.*)

Discoveries of the Seventeenth Century

The amazing discoveries which rewarded the early constructors of telescopes and microscopes in the seventeenth century attracted the attention of physicists to the theory of those instruments. The Law of Refraction was first correctly stated by Willebrod Snell (1591–1626), professor of Mechanics at Leyden, a preliminary step having already been made by Kepler, who in 1611 showed that for small angles the angle of refraction was proportional to the angle of incidence.

The truth that light travels with a limited velocity was suspected by Pierre de Fermat, of Toulouse (1601–65) and was accepted by Galileo, but no proof was forthcoming until 1676, when Olaus Römer calculated the velocity of light by observations of the occultations of Jupiter's moons.

Optics were a favourite study with Newton during the earlier years of his Cambridge professorship. By 1670 he had analysed white light by means of the prism into its component colours,[1] and had thus explained the colours of the rainbow. 'In consequence of a chapter of accidents he failed to correct the chromatic aberration of two colours by means of a couple of prisms; hence

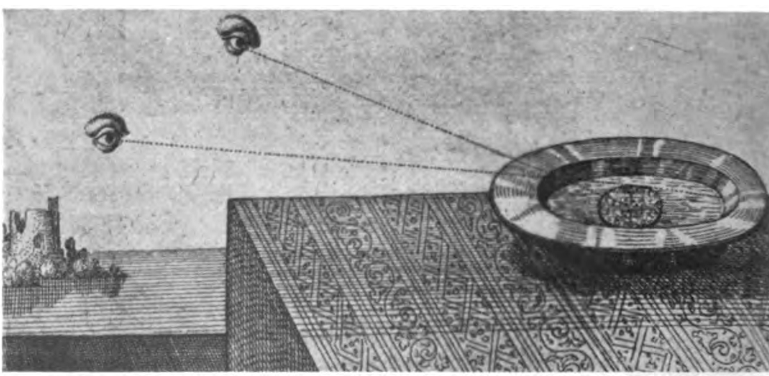
[1] Dispersion and the path of rays through a prism had already been investigated, *c.* 1600, by T. Hariot of St. Mary's Hall. Cf. MS. Addit. 6789, f. 206.

he abandoned the hope of making a refracting telescope, which should be achromatic, and, instead, designed a reflecting telescope, which is of a somewhat different design from those suggested by James Gregory and N. Cassegrain.'

Perhaps the grandest conception of the seventeenth century is that of the wave or undulatory theory of light. It assumes that light is transmitted by a series of waves in an ether which fills space, the waves being set in motion by the vibrations or pulsations of the luminous body.

The general description of the wave theory propounded in 1665 by ROBERT HOOKE was further extended by Huygens in 1678 and again in 1690.[1] From it the laws of reflexion, refraction and double refraction, were all deduced by Huygens: the phenomena of polarized light alone were beyond his powers of explanation; nor was it until the nineteenth century that Fresnel, by assuming the vibrations to be transverse, gave the world a satisfactory solution.

In Oxford, ROBERT FLUDD of Christ Church had not very much to say about optics, but he printed some good



FLUDD'S REFRACTION EXPERIMENT, 1617.
Macrocosmi Historia, i, p. 310.

engravings to illustrate the theory of vision and perspective. One of his pictures, illustrating a well-known effect

[1] Huygens, *Traité de la Lumière*, 1690.

of refraction, has been copied without acknowledgement so frequently, and in every school text-book, that it is doubtful whether those who now reproduce it, after three centuries, are acquainted with the original source of their illustration. As the first Englishman to have employed this illustration, Fludd deserves to be remembered.

Miscellaneous Optical Inventions and Instruments

Several optical inventions and theories were attributed to Sir Christopher Wren.

He was the first inventor of the process of drawing pictures by microscopical glasses. 'He has added much to the theory of dioptrics, and to the manufacture of good glasses and of other forms than spherical; has exactly measured and delineated the spheres of the humours of the eye, whose proportions were only guessed at before; . . . he discovered a natural and easy theory of refraction, showing not only the common properties of glasses but the proportions by which the individual rays cut the axis upon which the proportions of eye glasses and apertures are demonstrably discovered.'[1]

The study of refractions was one of the topics which Wren recommended to the attention of the Royal Society in 1664 in an address to that body. The Magic Lantern was already known at that time, for on 19 August, 1666, 'comes by agreement Mr. Reeves' to Samuel Pepys, 'bringing me a lantern with pictures in glass, to make strange things appear on a wall, very pretty'.

Among the physical toys of John Wilkins, the Warden of Wadham, was an engine for producing artificial Rainbows. A few gallons of water were forced through a narrow fissure so as to 'raise a mist in his garden, wherein a person placed at a due distance between the sun and the mist, might see an exquisite rainbow in all its proper colours'. (Plot.)

To this fruitful period belongs the epoch-making work of Robert Hooke, who as early as 1665 (*Micrographia*)

[1] Sprat, quoted in *D. N. B.*

realized that Light is a 'very short vibrative motion' transverse to straight lines of propagation through a 'homogeneous medium'. In the same work he published the first investigation on the 'fantastical colours' (interference colours) of thin plates and noticed the 'black spot' in soap bubble films.

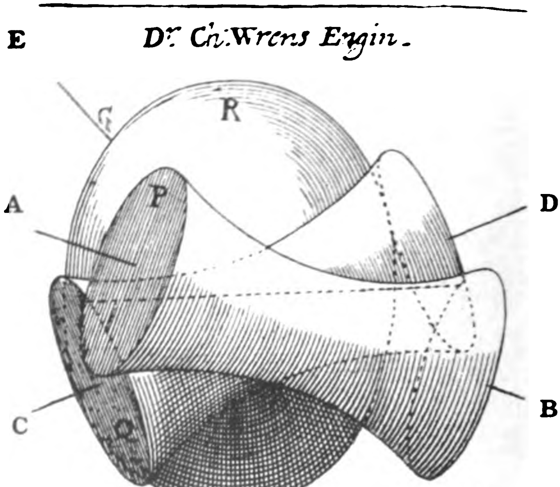
In 1669 Wren designed an ingenious machine for grinding lenses with hyperbolic curves—which he described to the Royal Society in the following terms.

'A Description

'Of Dr. Christopher Wren's Engin, designed for grinding Hyperbolical Glasses; as it was in a manner promised Numb. 48. *p.* 962.

'We shall give it in the Author's owne words, as followeth.

'Sint tria Corpora terendo idonea, *P. Q. R*; quorum *P.* & *Q.* sint æqualia & Columnari forma, *R* vero Corpus Lenti-forme. *P.* rotetur circa axin *A B*; *Q*, circa *C D*; & *R*, circa *E G*. Sint autem *A B* & *C D* in diversis Planis, ita tamen ut *E G*



producta, sit ad *rectos* angulos vtrique *A B* & *C D*: accedant denique ad se invicem Corpora, prout opus fuerit, servata tamen eadem inclinatione & situ Axium.

'Dico, ex revolutione & mutua attritione Corporum prius positorum exurgere noua corpora Geometrica, quorum *P* & *Q* erunt *Cylindroidea Hyperbolica* æqualia, *R*. vero *Conoides Hyperbolicum*, specie & magnitudine datum.

'Demonstrationem in promptu habemus, nec non Modulum ipsius Machinæ, terendis Lentibus Hyperbolicis destinatæ; quam operosa pictura & prolixa explicatione describere, mihi & artifici magis fuerit molestum, quam *Dædalo* cuivis sagaci similem ad-invenire. Postquam enim exposita jam sunt principia Geometrica, facile erit conjicere, quale sit Instrumentum; nempe, tres sunt Tabulæ oblongæ, planæ, validæ, labiles, & sibi invicem impositæ: Infima & Media sustinent *inæqualia* Capitula (sive Ansas mamphur sustinentes) alternatim posita; id postulat utriusque mamphuris obliquitas & quasi decussatio: Summæ Tabulæ *æqualia* sunt Capitula in longum Tabulæ disposita; & perforato citimo Capitulo mamphur transmittitur. Omitto rotas, rotulas, lora, pondera, cochleas, & reliqua admotum expeditum & Machinæ firmitudinem necessaria. *P* pertinet ad infimam Tabulam; *Q* ad mediam; *R*, ad summam. *R*, Lens est vitrea: *Q*, Modulus Lentem terens; *P*, Formula Modulum corrigens; quæ, dum motu obliquo, & diverso a motu tam Lentis quam Moduli, fertur, delet continuo & deterit, quicquid vitii imprimitur in Modulum ex Lentis & Materiæ attritione.

'Quare, cum adeo simplex & spontanea sit ista *Hyperbolici Conoidis* genitura, ex solis nempe motibus Circularibus; cumque motus sit duplex & varius, credibile est, Lentes *Hyperbolicas* ex hisce Principiis vel nullis fore explicandas.'[1]

Perspectographs

We now come to the consideration of a somewhat miscellaneous list of methods for copying or drawing views, and for projecting images of objects upon a screen, either for demonstration or for drawing.

As early as 1435 a frame crossed by threads was used by Leone Battista Alberti, when he wished to sketch. He viewed the landscape through the square meshes and then marked the outlines of the picture on squared paper. Alberti's method is fully described by Robert Fludd in 1617.[2]

For the purpose of obtaining a correct perspective, the early masters made use of a pane of glass or of a piece of gauze stretched vertically, upon which they could

[1] *Phil. Trans.*, 1669, pp. 1059–60. [2] *Macrocosmos*, p. 307.

delineate the contours of objects as seen from a fixed point of view.

Later this method was employed by Leonardo da Vinci, again by Albert Dürer in 1525,[1] and in a modified form by a Florentine painter, Ludovico Cigoli.

Cigoli first made a vertical perspectograph on the lines of Dürer's instrument, but then constructed a horizontal perspectograph in which, by a somewhat elaborate and delicate contrivance, the drawing was made on a horizontal surface. This invention was subsequently improved under the name of the **Diagraph** by Ronalds of Croydon in England, by Remenkampf in Germany, and by Gavard in France.

Many inventors turned their mechanical genius to the same problem. In Oxford, FRANCIS POTTER of Trinity invented a 'curious designe to drawe a landskip or perspective, but Sir Christopher Wren hath fallen on the same principle, and the engine is better work't'. The 'designe' was in the possession of John Aubrey in 1656.

In **Wren's Perspectograph** the drawing board was vertical and not transparent, and was arranged laterally in respect of the point of view. The drawing was made by a pencil carried on a rule forming one side of a parallelogram of which two sides are movable (the rule and the upper edge of the chassis keeping the same length). By this means the pencil has transmitted to it all the movements of a pointer, which can be moved by the artist so as to follow the outlines of figures in his field of view. Pepys recorded

> 'This morning (Apr. 30, 1669) I did visit Mr. Oldenburgh, and did see the instrument for perspective made by Dr. Wren, of which I have one making by Browne; and the sight of this do please me mightily.'

The contemporary illustration of the various activities of Chérubin's cherub-opticians clearly shows the prominent place that was occupied by the Perspectograph in the scientific mind during the latter half of the seventeenth century.

[1] Dürer, *Underweysung der messung mit den Zirkel*, Nuremberg, 1525.

CHERUBS USING PERSPECTOGRAPHS, TELESCOPE, BINOCULAR, AND MICROSCOPE, 1671.
Chérubin, La Dioptrique Oculaire.

Peep Show. **? 1700.**

Clarendon Laboratory.

View of the interior of a Library.

A model to illustrate the perspective of an interior view.

CAMERA OBSCURA

The discovery of the properties of the Camera Obscura, commonly associated with the name of Baptista Porta, is certainly much older than is generally supposed. Sun images formed on the ground under trees, especially during partial eclipses of the sun, must have been frequently observed by primitive man. It is practically certain that LEONARDO DA VINCI and the Benedictine monk DOM PANUPTIO observed the inverted image produced on the opposite wall by light entering a darkened room through a small hole in the shutter. GIAMBATTISTA DELLA PORTA, to give him his full name, id, however, describe improvements in magnifying glasses,[1] and appears to have invented the Portable Camera Obscura.

[1] *Magia Naturalis*, 1558.

Kepler had a Camera Obscura in 1620, which was thus described by a wandering Oxford scholar:

'I lay a night at Lintz, the metropolis of the higher Austria. There I found Keplar, a man famous in the sciences. . . . In this man's study I was much taken with the draft of a landscape on a piece of paper, methought masterly done: whereof inquiring the author, he bewrayed with a smile it was himself; adding, he had done it *non tanquam pictor, sed tanquam mathematicus*. This set me on fire. At last he told me how. He hath a little black tent (of what stuff is not much importing) which he can suddenly set up where he will in a field, and it is convertible (like a windmill) to all quarters at pleasure, capable of not much more than one man, as I conceive, and perhaps at no great ease; exactly close and dark, save at one hole, about an inch and a half in the diameter, to which he applies a long perspective trunk, with a convex glass fitted to the said hole, and the concave taken out at the other end, which extendeth to about the middle of this erected tent, through which the visible radiations of all the objects without are intromitted, falling upon a paper, which is accommodated to receive them; and so he traceth them with his pen in their natural appearance, turning his little tent round by degrees, till he hath designed the whole aspect of the field. This I have described to your Lordship, because I think there might be good use made of it for chorography: for otherwise, to make landscapes by it were illiberal, though surely no painter can do them so precisely.'[1]

The Portable Camera Obscura

A convex lens is mounted in a draw tube capable of being moved out or in so as to focus the image upon a horizontal sheet of ground glass after reflection in an inclined mirror. The ground glass screen is provided with a lid which can be lifted so as to keep off the light from the picture on the ground glass.

208. Portable Camera Obscura. **c. 1700.**

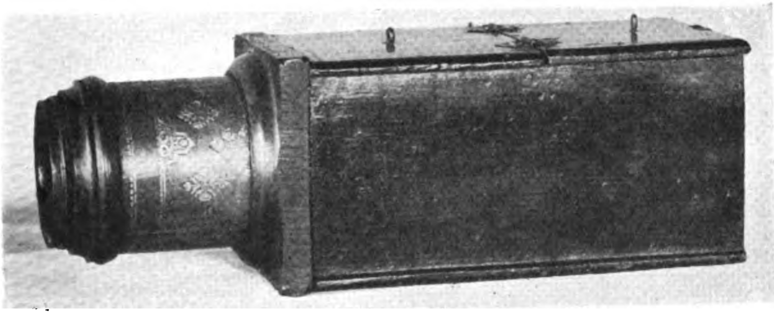
9 inches × $3\frac{1}{2}$ inches. Orrery Coll. 38.

Probably made by John Marshall.

This instrument is described in 1676 by J. C. Sturm in his *Collegium expt. curios.*, and again as a 'Cistula

[1] Wotton in a letter to Francis Bacon, dated Dec. 19? 1620, O.S.

catoptrico parastatica pro curiosis phaenominis' by Zahn in 1685. Lord Orrery's Camera is essentially similar. The lens is held in a cell of lignum vitae at the end of a draw tube covered with stamped leather. The stamps are identical with those used on the Marshall Telescope tube. The mount of lignum vitae was originally round: it appears to have been taken from some other instrument and to have been adapted to the front of the Camera Obscura. No doubt there was once a ground glass screen in the box, but this is now missing. Marshall



MARSHALL'S CAMERA OBSCURA, *c.* 1700.

is mentioned in 1710 as the maker of the Camera Obscura in the Tower of London by Uffenbach.

Such instruments were sold by Mr. Scarlet at his shop by St. Anne's Church, London, before 1738 (Smith's *Optics*, pl. 56).

In 1694 Robert Hooke showed to the Royal Society a portable Camera Obscura [1] for drawing landscapes, which in principle is like the later 'Camera clara'.[2] An early mention of the instrument also occurs in the Stowe MS. 748:

'I have got a very pretty Camera obscura that throws the figures erect and fit to be drawn upon a half-ground glasse plate.' Letter of Sir Godfrey Copley, London, 17 June, 1703.

In 1785 the Camera clara was described by the Leipzig optician Rheinthaler.[3]

In 1806 the **Camera lucida** was devised.

[1] Figured in Feldhaus, *Dictionary*.
[2] Derham, *Experiments of Hooke*, London, 1726, p. 295.
[3] Fresenius, *Gemeinnützige Kalenderlesereyen*, 1786, p. 62.

209. Sky Optick. **c. 1700.**

No. 32, Orrery Collection.

Diameter of globe 3 inches. Without lens or diaphragm.

After searching through many books in vain for an early account of this instrument I found it described and figured in 1671 by Father Chérubin as an 'Oculaire Dioptrique' to show sunspots and eclipses of the sun on a screen in a darkened room,[1] and again by Zahn[2] in 1685 as an 'Instrumentum aptum pro speciebus clarius in chartam in ducendis'.

Sky Optick, *c.* 1700.

The first recorded description in English is in Harris's *Lexicon Technicum*, 1704, under 'Obscura Camera'. 'Such ready fitted are now commonly sold on Ludgate Hill and are called Scioptricks.' Lord Orrery may have purchased his example at Marshall's shop which was on Ludgate Hill; but the name 'Sky Optick', by which Wright knew it when making the Inventory in 1731, does not appear in literature. In 1738–52 we find 'Scioptric' in Chambers' *Cyclopaedia*.

The uses of the instrument are thus described:

'For the convenience of directing the axis of the glass (of a Camera Obscura) towards any object, the Lens is placed in a large cylindrical Hole bored through the middle of a wooden Ball, called a Sky Optick-ball, which is easily moved about its centre, within a hollow wooden zone and fastened to the Window-shutter: This zone consists of two half zones screwed together in the middle after the Ball was let in; and the concavity of the zone hinders the light from passing between it and the Ball.'[3]

[1] Chérubin, *Oculaire Dioptrique*, 1671, p. 285.
[2] Zahn, *Oculus artificialis*, 1685, p. 168.
[3] Edm. Stone, *Supplement to Bion Instruments*, 1758, p. 266.

'For holding the lens, there is a little convenient apparatus to be had ready in the shops called a Scioptric Ball.'[1]

'A scioptric ball and socket being fastened against a hole in a window shutter in a darkened chamber.'[2]

210. Sky Optick, with circle of diaphragms. **c. 1780.**
Radcliffe Observatory.

211. Ditto. **18th cent.**
Clarendon Laboratory.

212. Sky Optick. **c. 1750–1800.**
Oriel College.

With convex lens mounted in ball of Lignum vitae.

? cf. Gehler, *Phys. Wörterbuch*, v, Leipzig, 1795, p. 82.

Miscellaneous Optical Apparatus

213. Convex ($6\frac{1}{2}$ in.) **and Concave** ($8\frac{1}{2}$ in.) **Spherical Mirrors.** **c. 1700.**
Orrery Collection 9.

On a stand. Such mirrors were a source of much mystification and amusement in early England.[3]

214. Concave Black Marble Disk.

Diameter 12 inches.

Found with the Orrery Apparatus at Christ Church.

This stone had apparently been used for polishing lenses according to the method described by Zahn, *Oculus artificialis: Telescopii practico-mechanici Fabrica*, p. 9, 1686. And a somewhat later writer recommended a 'piece of true black marble of the evenest grain and freest from white veins or threads' for putting the last polish on a speculum.[4]

[1] J. Harris, *Treat. Opt.*, 1764, p. 269.

[2] Imison, *Sch. Art.* i. 270. Further references: Ash, *Scioptic*, 1775, and G. Adams, *Nat. and Expt. Phil.* II. xv. 178, are given in the *N.E.D.*, but the derivation of the word from σκια, shadow + ὀπτικος, pertaining to vision, is not borne out by all early eighteenth-century spelling.

[3] W. A. Clouston, *Magic Mirrors*, Chaucer Soc. 1889, p. 332. Lane's Continuation of Squires Tale.

[4] Also cf. Smith's *Optics* (1738), p. 306.

It is, however, interesting to note that stone reflectors for astronomical purposes were made about 1825 by a process of marble-polishing invented by Alberto Gatti of Rome.

Gatti's process was reported upon by Biolcini, *Sopra alcuni Nuovi Riflettori lavorati in Roma per Uso di Grandi Telescopii*, 2nd edition, Roma, 1838; and in a *Rapporto della Commissione Accademica de' Lincei riguardante i Lavori Ottici del Signor Alberto Gatti*, 4to, 4 pp.

215. Bunsen's Spectroscope. **c. 1850.**

Magdalen College, Daubeny Laboratory.

By Elliott Bros., 30 Strand, London.

Presented by Justus von Liebig to Dr. Daubeny, after his visit to him in 1842, and by him bequeathed to the College.

Telescope and collimator are immovably fixed to the sides of a triangular mahogany box, supported on three brass legs. The hollow glass bottle-prisms, for use with high-refracting liquid media, are supported on a turntable in the box, adjustable by a long arm, swinging over a quadrantal scale of degrees, which can be read with a vernier.

Fraunhofer's Apparatus for exhibiting the Fixed Lines in the Spectrum.

No. 50, Royal Society.

Pres. by Fraunhofer of Munich.

216. Revolving bright ball Apparatus.

University Observatory.

Pres. by Professor C. Pritchard.

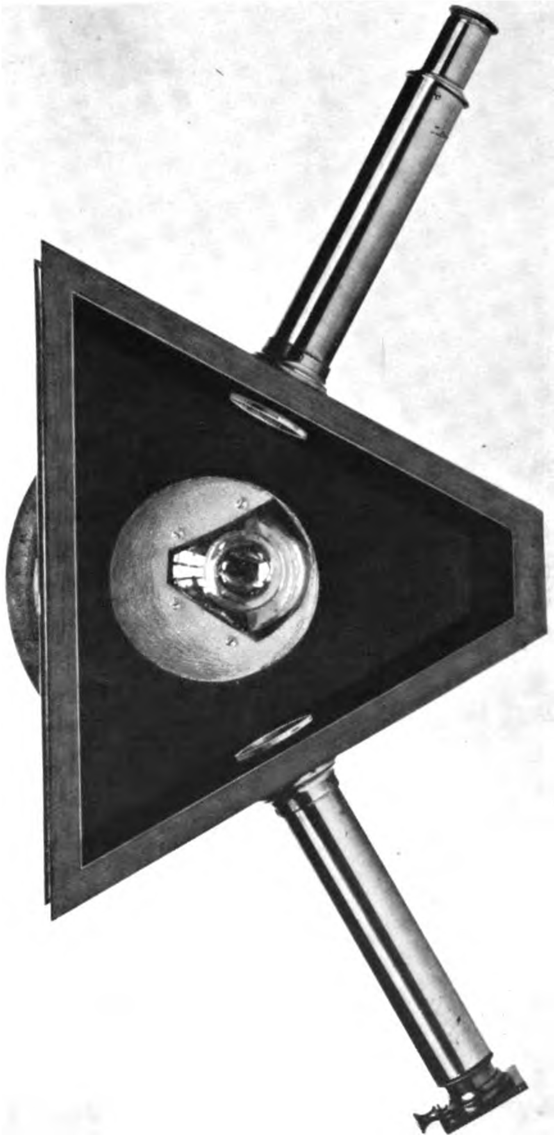
By Watkin and Hill.

PHOTOGRAPHY

217. Wet Plate Camera. **c. 1850.**

By J. J. Griffin, 10 Finsbury Square, London.

Used by Dr. Daubeny to illustrate his College Lectures and bequeathed by him with the contents of his laboratory to Magdalen College.



BUNSEN SPECTROSCOPE

Daubeny Laboratory, Magdalen College

218. Printing frames. **c. 1850.**

Magdalen College, Daubeny Laboratory.

By J. Cary, 181 Strand.

For use with the wet plate process.

219. Daguerrotypes (2). **c. 1840.**

Magdalen College, Daubeny Laboratory.

Views of Notre Dame and of the Chambre des Députés in Paris. The process was published in 1839.

220. Calotypes (2). **30 July 1842.**

Magdalen College, Daubeny Laboratory.

'Calotyped at Oxford By H. Fox Talbot', the inventor of the process.

Views of the greenhouses in the Botanic Garden and of Magdalen Tower.

221. Ronald's Photographic Recorder. **1854–78.**

Radcliffe Observatory.

Inscribed: 'Fra Ronald Inv Newman Inv'.

Figured and described by W. Crookes in *Radcliffe Report for 1854*.

MICROSCOPES

If we try to enumerate the individual examples of early microscopes which still remain to us, we find that they are so few that the oldest Compound Microscopes known to be in existence can be counted on the fingers of one hand: they are the Campani Microscope of 1686?; the Divini Microscope of 1668 in the Museo Copernicano at Rome; and the Leeuwenhoek Simple Microscope of about 1700 in the University of Utrecht. Other early types were the 'Hooke' Microscope, No. 504 in the Crisp Collection, and the Janssen Microscope found in Middelburg.

In England in 1664 Pepys acquired a microscope and a scotoscope.

> 'For the first I did give him £5 10. 0, a great price, but a most curious bauble it is, and he says as good, nay, the best he knows in England. The other he gives me, and is of value; and a curious curiosity it is to discover objects in a dark room with.'

The construction of the optical part of such instruments was described by J. C. Sturm [1] in 1676 and was again considered in 1685 by Zahn,[2] who describes the English, or Marshall microscope in a section headed 'Microscopy Anglicani Fabrica externa'.

The first English microscopes appear to have been made by John Malling of London, both with melted and with ground glasses of very small size. The magnification of the large microscope belonging to the Royal Society was over 10 diameters.[3]

The present author had the privilege and pleasure of discovering the oldest Oxford microscopes, dismantled, grey with the dust of ages, in a cupboard at Christ Church with other apparatus that had been bequeathed to the College by the Earl of Orrery. Their surpassing value consists in the fact that, not having been used for a century at least, they are preserved to us in their original state.

The earlier or Screw-barrel type of Microscope by Wilson had been preceded by the Hartsoeker (1694) instrument in which focusing was effected by the practical application of Bonanni's (1691)[4] screw-barrel arrangement acting on the object, which is clipped between two plates and pressed away from the object-lens by a spiral spring.

222. Pocket or Screw-Barrel Microscope. 1702.

Orrery Coll. 26.

By Wilson. Ivory body.

Complete with lenses, object forceps, &c., in shagreen case, as described in the *Phil. Trans.*, No. 281.

An exceedingly scarce instrument in so perfect a state.

223. Small Screw-Barrel Microscope. After 1702.

Clarendon Laboratory.

By (or after) Wilson.

[1] *Collegium Experimentale sive Curiosum*, p. 142.

[2] *Oculus artificialis*, 1685, p. 99.

[3] Grew, *Catalogue of the Rarities belonging to the Royal Society*, 1681.

[4] Bonanni, *Micrographia curiosa*, Rome, 1691, 4to, and Mayall, *Journ. Soc. Arts*, Sept. 1886.

224-5. Set of 7 ivory slides with 3 holes with microscopic objects:
and of **2 ivory slides with 2 holes,** empty. **1702.**
No. 39, Orrery Collection.

In box.

The slides are exactly like the one figured in the plate in Harris's *Lexicon*, 1704, and were obviously sold with the Wilson Screw-barrel Microscope of 1702. We are not acquainted with examples of microscopic preparations more ancient than these.

226. Double Microscope for viewing the Circulation of the Blood. **1693.**
No. 8, Orrery Collection.

By John Marshall.

This microscope is of the very greatest importance from the standpoint of the history of the instrument, on account of the extreme rarity of models of this period; and the historic value of this particular instrument is all the greater because it has been shut up in a cupboard with the rest of the Orrery apparatus since 1731. It is therefore likely to be in its original state.

The instrument, which agrees in all essentials with the model engraved in Harris's *Lexicon*,[1] is in excellent preservation, a portion only of the wooden eyecap being missing. There are only one or two original Marshall Microscopes in existence. Mr. Th. Court informs me that he is the owner of one, while another is said to have been in Sir F. Crisp's unrivalled (but now dispersed) collection of instruments.

There are none in the fine collection of Microscopes exhibited at South Kensington; and the reputed John Marshall microscope in the collection of the Royal Microscopical Society is clearly of much later date, as it has a body covered with polished shagreen, like the bodies of the Culpeper models of about 1735, and is also furnished with a Cuff pattern stage of about 1744, and has no ball-and-socket joint.

The Marshall microscope embodied several improvements that are still to be found in the best instruments

[1] Figured in Harris' *Lexicon Technicum*, 1704. This engraving is reproduced in Carpenter on the *Microscope*, edition of 1891.

of the present day—indeed, except for its uncouth proportions, it was essentially the first modern instrument as far as concerns the construction of the stand.

(1) There are both coarse and fine adjustments. The coarse adjustment is effected by moving the sliding socket up and down the pillar after having first unclamped the fine adjustment. The positions for the different powers are indicated by the corresponding numbers on the pillar. The fine adjustment screw is connected with the sliding socket supporting the arm, in which the body-tube is screwed.

In earlier microscopes focusing was effected solely by the direct movement of the tube or of the object either by rotating in a screw-socket (as in Hooke's and Wilson's microscopes) or by sliding in a cylindrical socket (as in Divini's and Chérubin's). Marshall's plan has been universally adopted by the best makers of large microscopes.

(2) The stage is provided with a fork, which is fixed to the pillar by a turn of a thumb-screw clamp. Thus the stage and the tube become parts of the same rigid system, and yet the stage is instantly exchangeable for another.

(3) A ball-and-socket joint is applied between the pillar and the base: thus the movements of inclination affect both object and body-tube alike, again as in all modern instruments. The ball and socket was borrowed from Hooke, the inventor, but whereas Hooke had used it to give inclination to the body-tube only, here it is applied at the lower end of the pillar, a very real advance.

The ball can be tightly clamped by the screw-collar, in which slots were cut to give spring. It has been inferred from a single example in which the slots were not cut that a few instruments may have been constructed before the slots were applied.[1] We do not consider that there is sufficient evidence for this view. The Christ Church Marshall has the slots.

(4) The condensing lens on a jointed arm is stated by Mayall to be the first application of such adjustments to the condenser.

The only real deficiency from the modern point of

[1] Mayall, *Journ. Soc. Arts*, 1886.

NO. 226. MARSHALL'S DOUBLE MICROSCOPE, 1693

Orrery Collection, Christ Church

view is the absence of the mirror. Marshall was certainly making microscopes in 1718 without this adjunct, and the first early instrument that is known with a mirror is a modified Marshall assigned to the period 1718–30—probably just a little earlier than the instruments of Culpeper—after which the mirror is hardly ever omitted.

Harris's engraving of the instrument shows that transparent objects were examined by the light of a candle placed in a position 'more favourable for depositing soot on the condenser than for illuminating the object'; and much ridicule has been heaped on this arrangement, but it is more likely that the application of ball and socket was for the very purpose of inclining the instrument away from the smoke from the candle. The base is heavily weighted with lead at the end opposite to the pillar.

According to Harris, Mellen's and Leeuwenhoek's simple microscopes were the best then in use, but he concludes his notice of Marshall's instrument thus: 'I have had Mellen's Glasses, and seen Lewenhoeck's and Campani's, but I would sooner have the Double Microscope (Marshall's) than any of them, and the price is much easier.'

The great size of the body of the tube may be explained by the fact that Marshall was in the first place a maker of telescopes, and that he adapted the tubes of the eyepiece of one of his telescopes to the purpose of his Double Microscope. The diameter of the eyepiece of the large Vellum telescope in the Orrery collection is 4¼ inches: the diameter of the body of the Marshall Microscope is 4 inches.

The Orrery instrument was lying about in detached pieces in a cupboard when I first saw it. The ball of the socket joint had been used as a sun for the Orrery or other astronomical model, the eyepiece had got mixed up with those of the telescopes, and it was long before I was able to fit the parts together and realize their unity and historic value. As it now stands it is perfect except for the loss of the wooden eyecap.

The leather-covered body-tube is tooled with bookbinders' stamps very similar to those upon a Marshall of 1715 which was found in the attic of the Physical

Laboratory at Jena,[1] and was No. 678 in Sir Frank Crisp's unrivalled collection of microscopes, of which he has kindly lent me an engraving.[2] The Orrery instrument, however, bears star-and-crescent stamps in addition to the others. The octagonal base, with a top of veneered walnut and sides covered with ebony carving, is of oak and contains a heavy weight of lead at one end to counterbalance the instrument at the other when it is swung out 'over the candle'.

The Accessory apparatus in a drawer consists of—

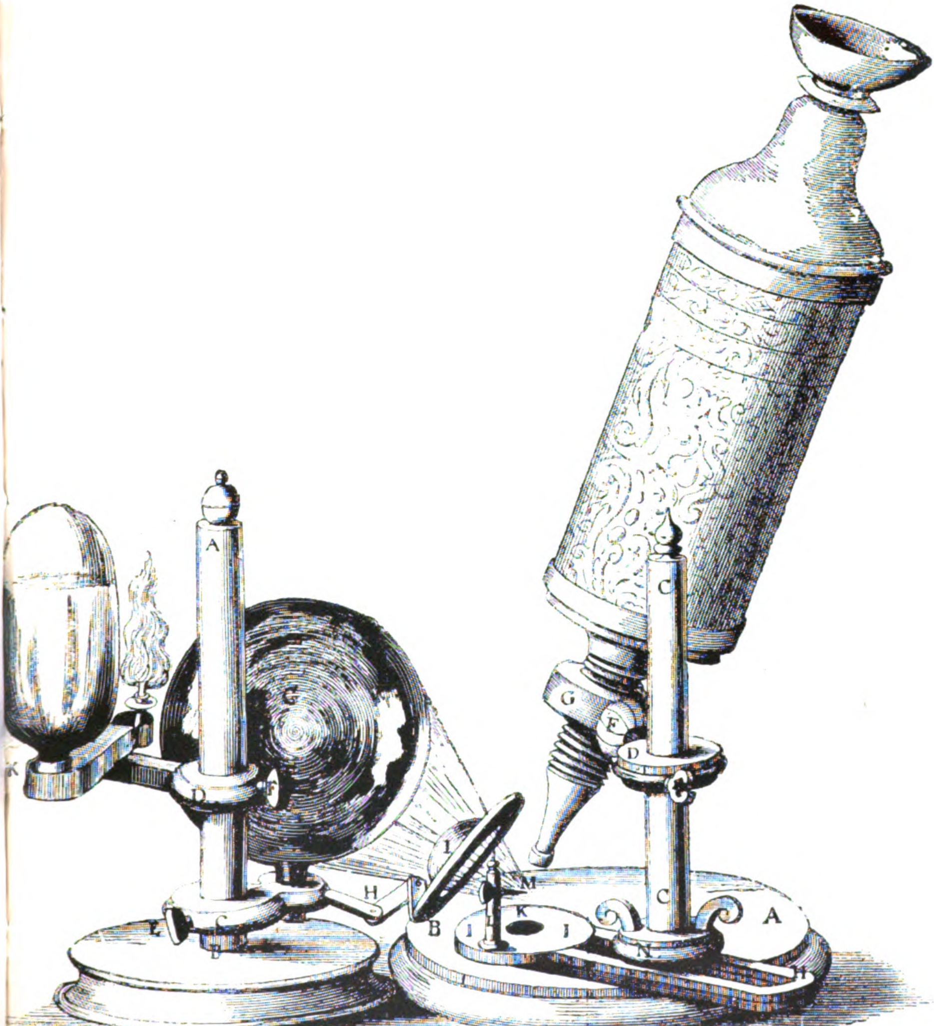
- Objectives, numbered 1–6. At the time these were considered a novel feature in connexion with a compound microscope.
- Stage with glass plate and a trough 'to be put on the Fish to hinder it from springing away, and moving its Tail out of the Light'.
- Stage with black and white grounds for the examination of opaque objects.
- Stage forceps and needle (steel) for sliding in loops under the second stage.
- Hand forceps of steel.

None of the early types of microscopes enumerated at the beginning of this section has a pillar stand, so that our Marshall instrument is the oldest microscope now in existence with the stand which is so important a feature in modern instruments—and it has it in all its perfection. The invention of the stand has not only increased the convenience in use but, as in the case of the telescope, has been a most important factor in the evolution of the microscope as a measuring instrument of precision.

What great advances it embodied may be gathered by comparing it with the design of other microscopes of the period, as for instance with the 'Microscopy Anglicani

[1] Doubtless several Marshalls went abroad. Travellers like Uffenbach, whose brother learnt lens-grinding from Marshall, would almost certainly have returned home with such useful inventions.

[2] Since these lines were written Sir Frank Crisp has died, and his magnificent collection of microscopes has been sold by auction and dispersed. Had Oxford had a Science Museum this collection, which he did not desire to see absorbed in the Royal Microscopical Society's series, might have been preserved among us, to the great gain of the history of British Science.

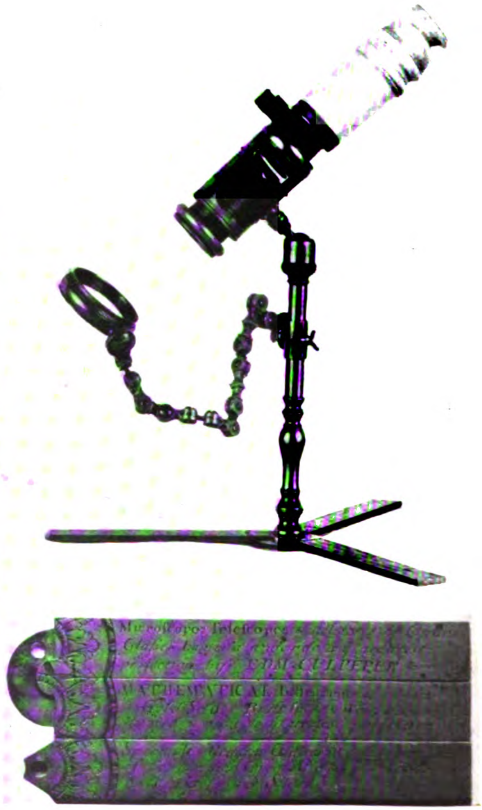


COMPOUND MICROSCOPE OF R. HOOKE OF CHRIST CHURCH, 1665

After Hooke's 'Micrographia' from Carpenter's 'Microscope'

NO. 228

NURENBERG MICROSCOPE



NO. 227

CULPEPER'S MICROSCOPE

Pitt-Rivers Museum

Fabrica externa' figured by Zahn, *Oculus*, 1685-6, and in J. C. Sturm's *Expt. Curios.*, 1676, p. 142.

As to the cost of early microscopes, C. Erndtel[1] has preserved to us *A Catalogue of Instruments which are Sold by Jan Musschenbrock at Leyden 1707.*

	Flor.	St.
An Universal Microscope	18	18
A Particular one	15	15
One to see the Circulation of the Blood with	07	10

By the middle of the eighteenth century the world had become 'full of microscopes some better, some worse'. Those that were reckoned to be very good were by Wilson, Campani and Divini, Leeuwenhoek, Hooke, Marshall, Culpeper and Scarlet, and Musschenbroek. And of these, HOOKE's instrument, figured in his *Micrographia*, is of special interest as being the design of an Oxford inventor. But we have no specimen of it in Oxford.

The next stage in the history of microscope construction that is illustrated by Oxford instruments is represented by the Culpeper Microscopes.

227. Culpeper's Microscope.

Ivory body on brass pillar stand. Pitt-Rivers Museum.

Marked E. Culpeper, Londini. (1666–1710)

The folding feet of the stand are engraved:

Microscopes Telescopes & all sorts of Optick Glasses Improv'd and made to ye greatest perfection by

EDM: CULPEPER & MATHEMATICAL

Instruments of all sorts in Gold Silver Brass Ivory & Wood accurately divided & made to ye greatest perfection.

Spectacles Reading Glasses in great Variety of Convex and Concave Glasses also Load Stones. Set in Gold and Silver &c.

228. Microscope with Wooden Body and Tripod.

? 1750.

Pitt-Rivers Museum.

A modification of the Culpeper and Scarlet model of 1738. Such microscopes are not uncommon. They

[1] Erndtel, *Relation of a Journey*, 1706–7.

were made at Nuremberg in large numbers and sold as presents for boys.

Cuff Model

The next four microscopes belong to a type, the invention of Cuff of Fleet Street, which was figured on a plate, dated 1744, in Baker's book on *Microscopes.* Cuff seems to have printed a descriptive pamphlet about it. It had a more delicate fine adjustment than any of its predecessors, and the characteristic 4-cornered stage was very accessible, far more so than in the tripod model of Culpeper and Scarlet, a point that was noted by Baker in 1753.[1]

Various manufacturers of microscopes appear to have taken up the construction of the Cuff model with minor modifications. We have in Oxford at least four, by Dollond, Adams, Nairne, and Jupp, and we have seen others marked 'Passemant, Ingénieur du Roi au Louvre, Paris' (described 1753); 'Cole, Maker, No. 136 Fleet Street, London.'

Adams' improvement consisted in applying a cradle-joint to the lower end of the pillar, on which the instrument could be inclined. Martin altered the attachment of the mirror. The instruments were generally packed in high pyramidal boxes: Nairne paid attention to the close packing of the microscope with a view to portability. Passemant of Paris added the ornamental scrolls beloved by the French during the eighteenth century.

229. Cuff's Double Constructed Microscope and Stand. ? 1761.

(By) Dollond, London. Christ Church.

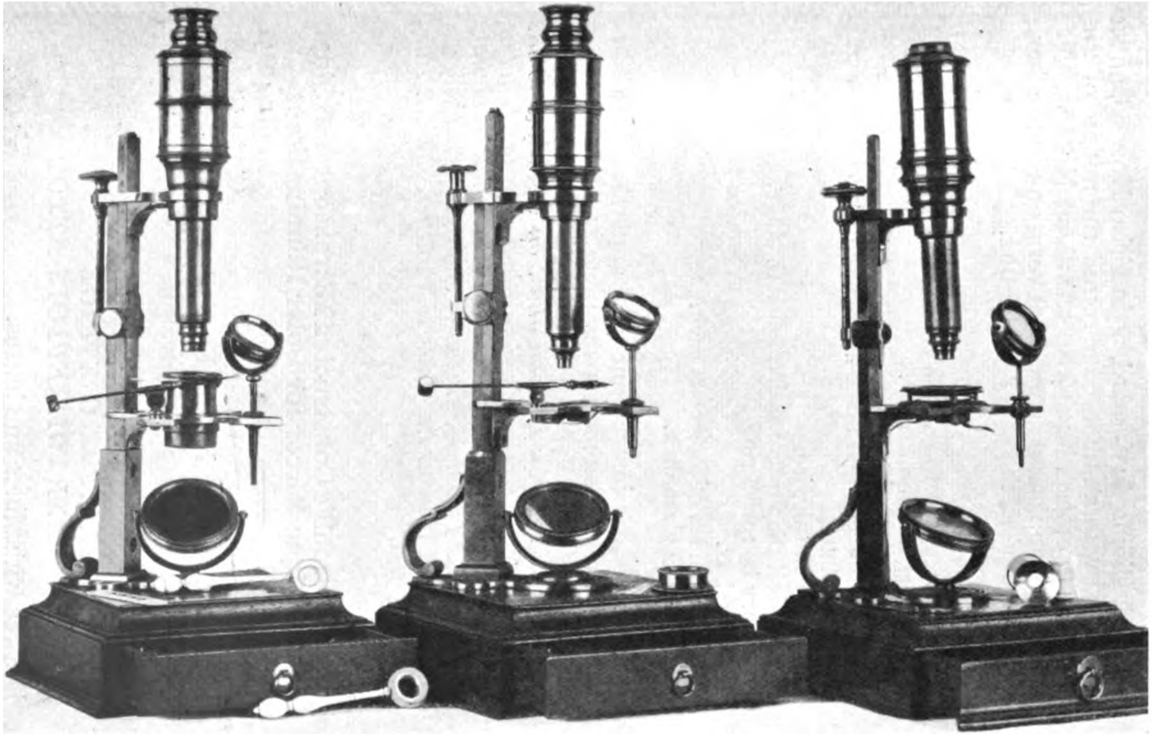
In pyramidal mahogany case. Inscription:

D.D. Joannes Tunnadine LL.D (? 1768–71).

(With MS. Catalogue of 6 ivory slides, each with four objects.)

This Dollond model is like a Cuff's Microscope No. 1, marked 'J. Cuff Londini inv^{t} et fecit' in the Crisp Collection (No. 558). It differs from Cuff's original model as described by Baker in 1753 in having a larger eye-

[1] Baker, *Employment for the Microscope*, 1753, pp. 442–6.



Cuff's Double Constructed Microscopes.

piece with sliding dust-guard, as in Crisp No. 739, and a raised band with a milled edge round the middle of the tube of the eyepiece, like Crisp's Dollond No. 695.

Accessory apparatus in two drawers, one in the base of the instrument, the other in the box.

Objectives—Nos. 1–6.
Eyepiece, screwing, with sliding dust-guard.
Lieberkuhn and carrier.
Spring stage object holder.
Stage forceps and black and white disk.
Fish plate.
Brass spiral wire.
Conical diaphragm fitting beneath stage.
Ivory box with rings.
Live box.
Ivory slides of four cells each.
Concave glass disk.

This particular instrument and apparatus is accompanied with a sixteen-page pamphlet by Dollond. '*A Description of the compleat Microscopic Apparatus: as made and sold by John Dollond and Son Opticians to his Majesty . . . Near Exeter Exchange in the Strand London.* 1761.' '*Description de l'Apparate Microscopique contenant les Microscopes Doubles, Simples et Solaires par Pierre et Jean Dollond, demeurant dans le Cimetière de St. Paul à Londres*' n.d.

230. Cuff's Double Constructed Microscope and Stand with Oblique Mirror for Solar Illumination.

1746–71.

Christ Church.

(By) G. Adams at No. 60 Fleet Street, London (who died 1798).

Inscription on silver plate:

ΘΑΥΜΑΣΤΟΣ Ο ΚΥΡΙΟΣ
ΕΝ ΠΑΣΙ ΤΟΙΣ ΕΡΓΟΙΣ ΑΥΤΟΥ

Drawer with slides and lenses.

The instrument is described by G. Adams, *Micrografia Illustrata*, Pl. 6.

231. Cuff's Model Microscope. 1772–3.

Oriel College.

Nairne London Inv^{t}. et Fecit.

Portability and close packing were leading objects with Nairne. In this instrument the box itself is made to serve the purpose of a stand. The pillar is fixed by a cradle joint to the bottom of the box. When not in use, the microscope is turned down between the ledges that carry the accessory apparatus. The front of the box slides out, to make room for the mirror.

List of Accessories:

Objectives—Nos. 1–6.
Eyepiece 1, with a sliding dust-cap.
Cone diaphragm.
Lieberkuhn in box and sliding carrier tube.
Spring stage.
Fish plate.
Stage forceps.
Hand forceps.
Ivory box with rings and talc covers.
Live box.

232. Compound Microscope on Tripod Stand.

Clarendon Laboratory.

By Jupp. With Cuff stage.

233. Microscope.

University Museum.

By Pritchard 312 Strand.

Engraved, 'Ash. Mus. Oxford.'

With short 3 in. tube on folding tripod stand.

Set of four sapphire Magnifiers in box, marked 20–80. With MS. directions for cleaning.

Set of four lenses in blacked ivory cells.

234. Modern Microscope.

Clarendon Laboratory.

By Elliott.

235. Modern Microscope.

Radcliffe Library.

By Powell and Leland.

List of Names of Makers noted on Microscopes in the Crisp Collection. On 18th or very early 19th Century Models

George Adams [senior] at Tycho Brahe's Head in Fleet St. London.
Universal Microscope 1746.
Variable Microscope 1771.

J. Ames [formerly an assistant in the Polytechnic Institution] near Bristol.

G. Amici Modena. Author of *De Microscopj Cata diottrici* 1818.

Bancks 440 Strand London.

Banyon Norwich.

Bate London.

Bithray Royal Exchange, London.

J. Blexler Ludgate Street, London. [Maker of Jones Model Microscope.]

J. Braham 10 St. Augustine's Parade, Bristol. [Microscope probably made by Cary.]

G. F. Brander Augsburg.

Brander & Höschl in Augsburg.

Brock invenit et fecit London.

Joseph Brum Opticus in Instituto Bononia 1772.

Elaboratum Blasio Burtini Venetiis Optico.

P. Carpenter fecit 24 Regent St. London.

Cary London.

Vincent & Charles Chevalier Quai del'Horloge, Paris *c.* 1835.

Jacobus Clark Dundee fecit. I. Clark fecit Edin[r].

G. Cremer Groningae fecit.

Crichton London.

T. Crickmore Ipswich.

I. Cuff London.

Culpeper & Scarlett Fleet St. London.

J. Cuthbert London 1829.

J. P. Cutts, Optician to her Majesty Sheffield.

C. F. Dellebarre 1806 Onderdewjwgaart Canzuis confecit Delft.

Dennis 118 Bishopsgate St. London.

G. & C. Dixey 78 New Bond St. London.

W. Duncan Aberdeen.

J. D. Fokkenberg fecit Utrecht 1777.

E. G. Francis 92 Berwick St. Soho.

Gilbert & Son London.

HARRIS & SON Fleet St. London. [Some of his unfinished instruments were sold in 1887 by his grandson Th. Harris.]
HILLUM 109 Bishopsgate St. Within, London.
HUNTLEY 52 High Holborn, London.
PIETER JEWEL Middelburg.
W. & S. JONES 30 Holborn. [Before 1798.]
J. M. KLEMAN fecit Amsterdam.
LÉRÉBOURS Opt^{cn} de l'Empereur et Roi, place du pont Neuf à Paris.
LINCOLN London.
GEO. LINDSAY inv. et fec. 1742.
I. MANN fecit.
BENJ. MARTIN Newton Head Fleet St. 1760–71. Author of *Optical Essays*.
MILLER & ADIE Edinburgh.
L. NEWMAN 122 Regent St. London.
OBERHÄUSER Paris.
JOHANN BALTHAZAR OPPELT opticus zu Anspach in Francken.
A. PRITCHARD 13 Picket St. London.
THO. RUBERGALL Opt^{n} to H.R.H. the Duke of Clarence 24 Coventry St. London.
ED. SCARLETT Soho, London.
C. V. SCHLEENSTEIN à Cologne.
DOMENICO SELVA Venice.
SHUTTLEWORTH *c.* 1785.
J. SISSON London. [Maker of 'Dr. Demainbray's Invent.' 1756.]
Ex officina Io. GOTTL. STEGMANNI Cassell.
TECKER à Paris.
TIEDEMANN Stuttgardt.
F. VILLETTE à Liege.
F. WATKINS London.
WATKINS AND HILL Charing Cross London.
T. WINTER 9 New Bond St. London.

ELECTRICITY AND MAGNETISM

MAGNETIC COMPASS

Introduction

Many nations, the Chinese, the Arabs, the Greeks, the Etruscans, the Finns, and the Italians have each in their turn been credited with the discovery of the Compass. There has been a tendency to push the invention of this instrument farther and farther back into the past, and thus it has acquired a mythical origin in which all record of the real inventor has been lost. Modern research has failed to find any convincing account of the properties of the lodestone, 'a stone with which an attraction can be given to a needle', before A.D. 121, and though as remote an antiquity as 2634 B.C. has been attributed to the compass of the Chinese, the first authentic record of a Chinese marine compass is no older than A.D. 1297, three centuries after the floating compass was in use among the citizens of Amalfi.

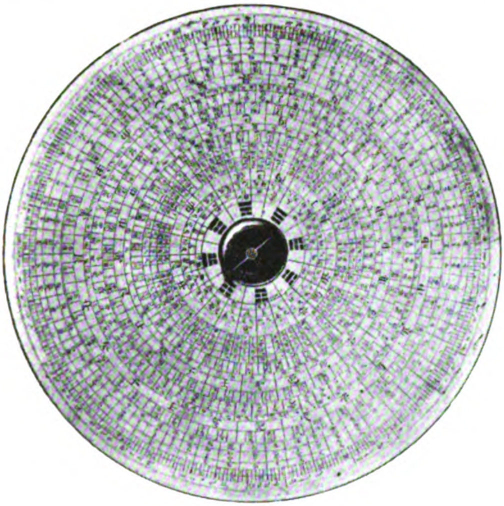
It has recently been argued[1] that the 'South Pointing Chariots' or Indicators of the South, which were used by the very early Emperors of China on their journeys, and have been supposed by Padre Bertelli and others to have been magnetic needles, were merely mechanical contrivances used for indicating the south which depended for their orientation on cogwheels rather than upon magnetism.

In its construction the Chinese compass differs from the European instrument in having a mark upon the south-seeking pole of the magnet instead of upon the north, and in having the compass dial graduated into 24 points, starting from the South Pole. Specimens of such instruments with short and very sensitive needles are preserved in the Bodleian Library and in the Pitt-Rivers Museum.

The floating type of compass was undoubtedly much

[1] Professor Giles, *Adversaria Sinica*, Nos. 4 and 7.

used in the East at an early period. Navigators in Indian waters were said to use 'a sort of fish made out of hollow iron, which, when thrown into the water, swims upon the surface, and points out the north and south with its head and tail'.[1] And in 1242 the magnetized needle, floated on water by a piece of wood, was employed by seamen in the Eastern Mediterranean, and by the Italians, whose name *calamita* has been supposed



CHINESE COMPASS.
From R.G.S. Collection.

to have been derived from καλαμίτης, a frog, and thus to be a memento of their early practice.

Magnetic needles 'of sixe ynches long, and longer, upon a pinne in a dish of white *China* earth filled with water' were used in eastern navigation in the sixteenth century.[2] It has been conjectured that the Arabians may have brought the compass from the East to Europe.

There are many references to the polarity of the magnet in European literature of the Middle Ages. The

[1] Bailak Kibdjaki, *Merchant's Treasure*; Klaproth, *Lettre*, p. 57, quoted from Ency. Brit., Art. *Compass*.
[2] Wm. Barlowe, *Navigator's Supply*, 1597.

earliest mention of it is found in the works of the Arab geographer Edrisi (*c.* 1099–1154).[1] Alexander Neckam, of St. Albans (1157–1217), foster-brother to King Richard I, gives a more detailed account. In his *De Utensilibus* he describes a compass of which the needle turned on a pivot. French crusaders brought to Europe descriptions of the floating compasses ordinarily used in the East; two floats were used to support the needle in one type of compass used in 1248 (Hugo de Bercy).

An early visitor to Oxfordshire, Brunetto Latini,[2] was acquainted with the compass and possibly brought the first compass to that town about 1260, and his pupil Dante refers to the needle pointing towards the pole star.[3] Roger Bacon's compass was a lodestone swimming on water.[4]

But the first scientific treatise on the magnet, the *Epistola de magnete*, was written at Lucera in 1269 by Petrus Peregrinus de Maricourt. This work was evidently familiar to Oxford students of the time, for there are seven copies of the MSS. at Oxford, a quarter of the whole number (28) known to Sylvanus Thompson. One of these copies,[5] written in the reign of Edward II, formerly belonged to Merton Priory, near London. It contains a clearly drawn diagram, which is believed to be the oldest figure of a pivoted compass needle now in existence.

'The first part of the epistle deals generally with magnetic attraction and repulsions, with the polarity of the stone, and with the supposed influence of the poles of the heavens upon the poles of the stone. In the second part, Peregrinus describes first an improved floating compass with a needle thrust through a pivoted axis, placed in a box with transparent cover, cross index of brass or silver, divided circle, and an external "rule" or alhidade provided with a pair of sights.'[6]

Peregrinus also gives an interesting description of a 'wheel which shall be constantly in motion', which owes its motive power to a small magnet contained within

[1] Hallam, *Middle Ages*, iii, chap. 9.
[2] *Livres du trésor* (i, pt. ii, ch. cxx, p. 147, Paris edit. 1863).
[3] *Paradiso*, xii. 28-30.
[4] *Opus majus* and *Opus minus*, 1266-7.
[5] MS. Ashmole 1522. [6] Quoted from S. Thompson.

a silver box. It does not, however, appear that he actually constructed such a machine.

The dates given above show that it is a mistake to attribute the invention of the compass to the year 1302 by one 'Flavio Gioia' of Amalfi, and it has recently been shown that this name is merely an alteration of that of

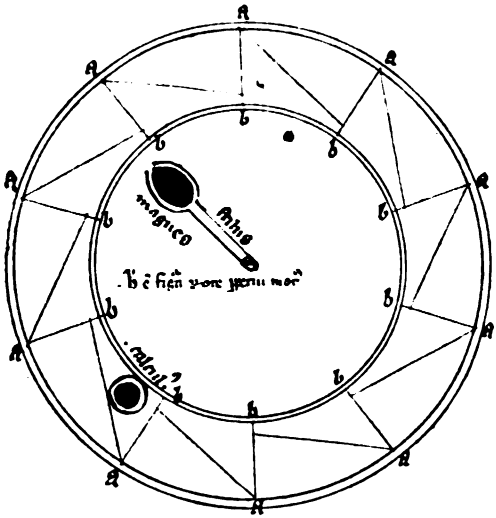


FIGURE OF A MAGNETIC PERPETUAL MOTION MACHINE DESIGNED BY PEREGRINUS.

MS. Ashmole 1522, c. 1350.

an early historian, Flavio Blondini, who while merely noting the fact that Amalfitan sailors used compasses, has been taken to be the actual inventor.

With the compass to guide them, mariners could from now onward abandon the old-world method of navigation which was hardly more than coasting, and the triumph of oceanic discoveries may well be claimed for this little instrument, for without the confidence inspired by its sure guidance, Columbus, Magellan, and Vasco da Gama would scarcely have ventured out into a vast and unknown track of waters. The voyage of Columbus in its turn reacted upon our knowledge of terrestrial magnetism by leading to the discovery of the magnetic variation.

The successive improvements connected with the compass have been noted by Sylvanus Thompson, and we may mention as the first of them the addition of the compass card.

The compass card is an adaptation of the *Rosa Ventorum* or diagram of the direction of the principal Mediterranean winds. Early wind-roses, as marked on the *portulani* or sailing charts, show the directions of the Tramontano, Greco, Levante, Scirocco, Ostro, Africo (or Libeccio), Ponente, and Maestro. The East is frequently marked with a cross instead of L (for Levante), a sign that survived in many English compasses till about 1700. The North, first marked with a broad arrowhead, and with a T (for Tramontano) about 1492, gradually came to be denoted by a combination of both marks which has grown into the familiar and universal *fleur-de-lys*.

The original divisions of the compass card into the *Rosa Ventorum* were further amplified into the 32 points of the compass card as we know them at the present day: this division is at least as old as Chaucer[1]: 'Ship men rikne thilke partiez in xxxii'. And to these points or rhumbs names were given probably by Flemish seamen.

An improvement, said to be due to the Amalfitans, is the mounting of the compass card upon the needle, to turn with it. Sailors use a compass at the 'middle of which is pivoted a wheel of light paper to turn on its pivot, on which wheel the needle is fixed and the star (windrose) painted'.[2] The types of instrument used by the fifteenth- and sixteenth-century navigators have been figured by Laussedat[3] and Dudley.[4] The placing of a fixed card at the bottom of the box, below the needle, was practised by the compass-makers of Nuremberg in the sixteenth century and by Stevinus of Bruges about 1600.[5]

[1] Chaucer, *Astrolabe*, 1391.

[2] Da Buti, the Dante commentator, 1381. *Ency. Brit.*, Art. 'Compass'. A compass-card moving with the needle was called a 'fly'. *D. N. B.* [3] Laussedat, *Recherches sur les instruments*.

[4] Dudley, *Arcano del Mare*.

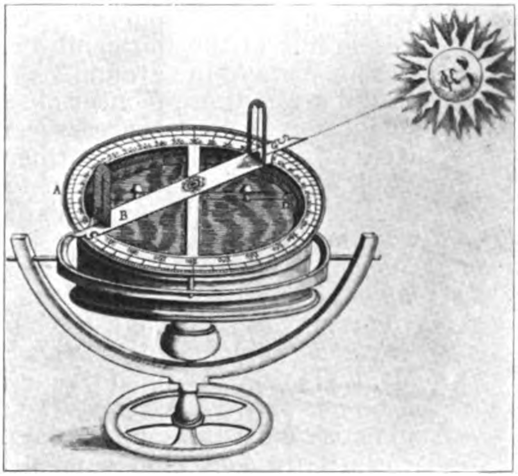
[5] Early Compasses by the following English makers are represented in the Lewis Evans collection: Henry Sutton 1661, B. Martin *c.* 1750, Christopher Earle (?), Will. Collier (before 1712), John Sellers *c.* 1660, John Bennett of London, *c.* 1700. Capt. Creagh-Osborne has one by Scatliff of London, *c.* 1760.

The earliest description of gimbals or rings for suspension, pivoted at right angles to one another, is said to have been written about 1604.

Since the beginning of the seventeenth century the improvements that have brought the mariner's compass to the present state of perfection are chiefly due to the genius of two men, GOWIN KNIGHT, Fellow of Magdalen College, Oxford, and LORD KELVIN.

In 1616 the 'most admirable and usefull instrument of

PIGAFETTA'S COMPASS, 1518.
After Laussedat.



DUDLEY'S SHIP'S COMPASS, 1646.
Arcano del Mare.

From blocks lent by R. G. S.

the whole world', the compass needle, was described by WILLIAM BARLOWE (*c.* 1544-1625) of Balliol College, who has the merit of having been the first to print the word **magnetisme** in the English language, as 'so bungerly and absurdly contrived, as nothing more'.[1] The form for the needle should be 'a true circle, having his axis going out beyond the circle, at each end narrow and narrower, unto a reasonable sharpe point, and being pure steele as the circle itself is, having

[1] Barlowe, *Magneticall Advertisements*, p. 66. Ant. Wood thought very highly of Barlowe's industry in searching out many 'rare and magnetical secrets'.

in the middest a convenient receptacle to place the capitell in'.

In 1657 Wren referred to magnetics as a British invention, i.e. as far as knowledge of the inclination[1] and variation of the needle are concerned, for he naturally did not claim for us the invention of the compass.

The name of EDMUND GUNTER of Christ Church is often mentioned in connexion with the discovery of Magnetic Variation. On June 13, 1622, at Limehouse, he made eight observations which showed that the Variation of the Compass, already known to Peter Peregrinus in the thirteenth century, itself **varied** 'in various parts of the ground'.

And it was these pioneer observations that doubtless stimulated Gunter's successor in the Gresham chair, Henry Gellibrand, to go farther into the matter. The result was the publication in 1636 of the discovery of the Secular Variation of the Variation (as the Declination was then called), in the first important treatise on the subject, *A Discourse mathematical on the variation of the magneticall needle*, London 1636.

'Magnetics' became a topic of special interest to the Royal Society in July 1664. Sir Robert Moray and Mr. Balle suggested many experiments in which HOOKE also took part. As regards the relative lifting power of an entire lodestone, and of that of the pieces into which it can be broken, Hooke mentioned that he had seen a little lodestone lift up 150 times its own weight. By April 1666, he had tabulated the degrees of a lodestone's attraction at varying distances from the pole of a magnet, but further observations were hindered by the fact that Mr. Balle had gone off with some of the magnetic apparatus belonging to the Society. A few weeks later Hooke demonstrated the course of lines of magnetic force by iron filings.

Some experiments were made with two lodestones, one a terrella, the other of an irregular figure. Some steel-dust being scattered about them, there appeared upon the different position of the latter in respect of the former, different and odd postures in the steel-dust.

[1] The *inclination* of the needle was discovered in 1546 by G. Hartmann, the maker of one of the St. John's astrolabes, and again by Robert Norman in 1576.

Mr. Hooke was ordered to describe these postures in schemes, and to bring them in to the Society.

At the meeting on April 25, Hooke had already demonstrated the oval course of lines of force or 'lines of direction' as he called them, by a small movable magnetic needle. In 1684, he showed that steel rods can be magnetized by heating them and then cooling them in the magnetic meridian. The first magnetic map with lines of equal variation was constructed by EDMUND HALLEY of Queen's College, in 1700, to whom also the first historical account of the *Aurora borealis* is due.

A prevision of the **Electric Telegraph** in the seventeenth century is another example of how far the brighter minds of the period were in advance of their time.

Curiously enough, both writers belonged to Exeter College, a college that was not otherwise very closely associated with the work of early Oxford scientists. Firstly GEORGE HAKEWILL, after describing the use of the mariner's compass in his *Apologie* in 1627, goes on to mention 'another excellent invention sayd to be lately found out upon the loadstone', suggesting the use of magnetic needles for telegraphy. As Hakewill subsequently became Rector of his College, it is not impossible that his writing may have suggested the subject to Glanvill who came up to Exeter about 1652.

JOSEPH GLANVILL (1636-80), afterwards a member of Lincoln College, and one of the first members of the Royal Society, happened upon a passage in Van Etten's *Récréation Mathématique* in which the possibility of the transmission of news by the use of a magnet is mentioned. But the world remained very sceptical about the matter, until Glanvill, who had had his mind opened by his 'philosophical considerations touching witchcraft', clearly showed how such telegraphy could be effected, and 'without unwarrantable assistance from demoniack correspondence'.

'Let the friends that would communicate take each a dial, and, having appointed a time for their sympathetic conference, let one move his impregnate needle to any letter in the alphabet, and its affected fellow will precisely respect the same. So that, would I know what my friend would acquaint me with, 'tis but observing the letters that are pointed at by my needle, and in their order transcribing them from their

sympathized index, as its motion directs; and I may be assured that my friend described the same with his, and that the words on my paper are of his inditing. . . .

'By some other such way of magnetick efficiency . . . 'tis not unlikely but that present discoveries might be improved to the performance.'[1]

It may here be remarked that the **tellograph** was the invention of a member of Brasenose College,[2] who had some reason for wanting to learn the result of a race at Newmarket in 1794. He was not an electrician.

At the beginning of the eighteenth century, several of our Oxford natural philosophers were keenly interested in magnetism and electricity. Professor DAVID GREGORY had investigated the Laws of Magnetic Action in 1693. JOHN KEILL, whose lectures on Physics have already been mentioned, gave reasons for believing that the magnetism of a lodestone is due to the structure of parts, and supported his view by the experiments of deforming a lodestone by striking it and of thus altering the position of its internal parts and its magnetic directions, and of destroying the magnetism of a lodestone by heating it in the fire. He concluded that 'notwithstanding all these things, the magnetick virtues must still be reckoned amongst the occult qualities'. DESAGULIERS (cf. p. 198) must also be mentioned, although most of the electrical experiments for which he was honoured—he was given three Copley medals—were performed after his removal from Oxford to London. He was the first to classify bodies as *electrics* or non-conductors, and *non-electrics* or conductors. But his eminent services to the Science of Electricity did not save him from a sad end:

> Can Britain . . .
> . . . Permit the weeping muse to tell
> How poor neglected Desaguliers fell?
> How he, who taught two gracious kings to view,
> All Boyle ennobled, and all Bacon knew,
> Died in a cell, without a friend to save,
> Without a guinea, and without a grave?
>
> Cawthorn, *Vanity of Human Enjoyments*, v. 147–54.

[1] *Scepsis Scientifica or the Vanity of Dogmatising recast.* 1661.
[2] Richard Lovell Edgeworth, the father of Maria Edgeworth.

To the many notable successes of the scientific members of Christ Church must be added that of the construction of the first **Electric Battery.** Dr. John Bevis (1693–1771), a considerable astronomer, who fitted up an observatory at Stoke Newington *c.* 1738, and who would have been better known, had not his publisher gone bankrupt on the eve of the publication of his *Uranographia Britannica*, was also much interested in practical electricity. His name should be inseparably connected with that of Sir William Watson in connexion with the Leyden Jar, that wonderful vessel which 'when well electrified, and you apply your hand thereto, you see the fire flash from the outside of the glass wherever you touch it, and it crackles in your hand'. To this jar, concerning which Musschenbroek remarked 'For the whole kingdom of France, I would not take a second shock', Bevis contributed the outer coating of tinfoil, replaced the water, that had previously been employed as an inner conductor, with leaden shot, and demonstrated that the violence of the discharge varied directly with the number of jars in metallic connexion. His, therefore, is the distinction of having constructed, and demonstrated the use of the first electric battery. We wonder how many of the present members of the House have ever heard of him.

About the same time more special attention was being given to processes for the manufacture of magnets. In 1730 Servington Savery was held to have given to the Royal Society a 'very honest and plain account' of magnets and how to make them,[1] and in 1744 Dr. Knight exhibited still stronger magnets of his own making at a meeting of the same Society. His twelve steel bars lifted up 23 lb. 2½ oz.[2] General interest was also taken in an armed Terrella which is said to have lifted 40 lb. This was presented by the Earl of Aberdeen to the Royal Society. Both Savery and Knight were members of Magdalen College.

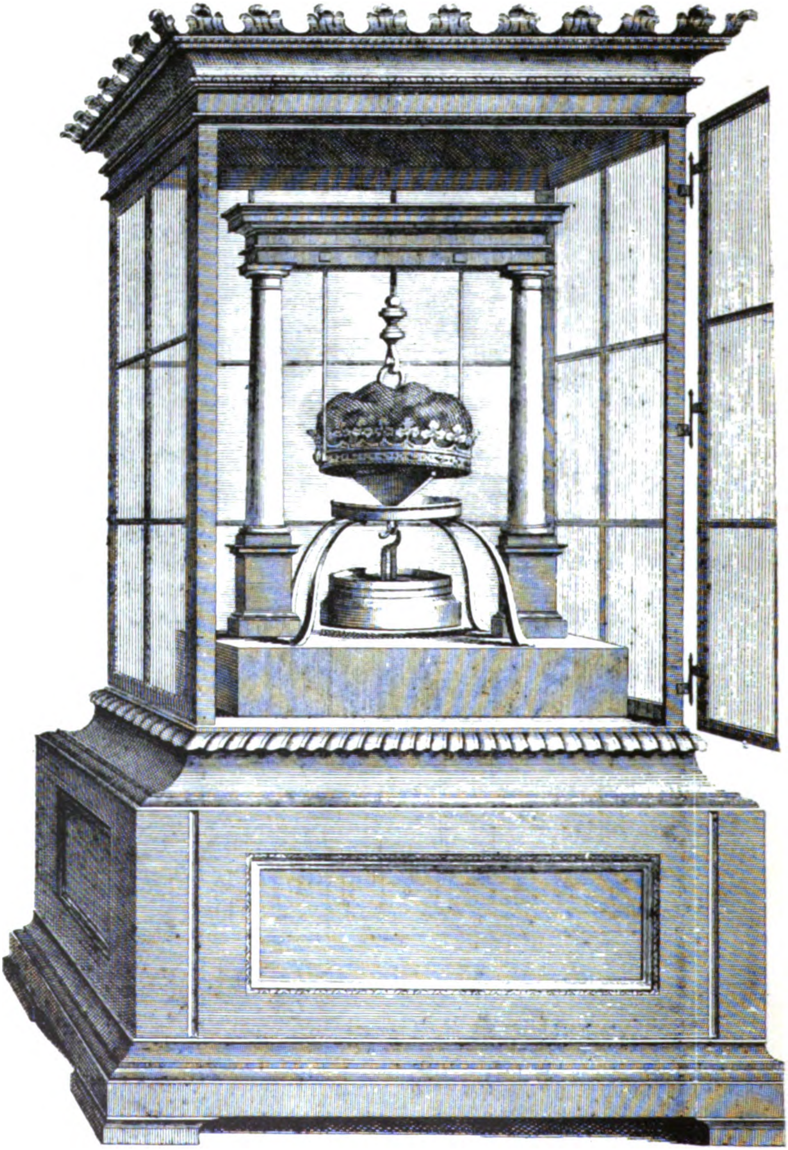
In 1750 the needles of merchant ships were made of two pieces of steel bent in the middle and united in the shape of a rhomb. For these Dr. Gowin Knight pro-

[1] Savery, *Magnetical Observations and Experiments*; *Phil. Trans.*, xxxvi, 1730.
[2] *Phil. Trans.*, lxvi, 1776.

posed to substitute straight steel bars of small breadth, suspended edgewise and hardened throughout. He showed that the Chinese mode of suspending the needle conduces most to sensibility. Dr. Gowin Knight's method of making artificial magnets for the mariner's compass was long kept a secret, and it appears to have been lucrative. The secret was not communicated to the world until Canton (*b.* 1718), a weaver of broad-cloth at Stroud, had freely and candidly exhibited his own experiments to the Royal Society, for which he was awarded the Copley Medal in 1751. By Gowin Knight's process a large quantity of clean iron filings was put into a capacious tub about half full of clear water. The tub was then agitated to and fro for several hours, until the filings were reduced by attrition to an almost impalpable powder. This powder was then dried and formed into paste by admixture with linseed-oil. The paste was moulded into convenient shapes, and exposed to a moderate heat until they attained a sufficient degree of hardness. 'After allowing them to remain for some time in this state, he gave them their magnetic virtue in any direction he pleased, by placing them between the extreme ends of his large magazine of artificial magnets for a second, or more, as he saw occasion. By this method, the virtue they acquired was such, that when any one of those pieces was held between two of his best ten-guinea bars, with its poles purposely inverted, it immediately of itself turned about to recover its natural direction, which the force of those very powerful bars was not sufficient to counteract.'[1] After his death in 1772, either makers of compasses became careless, or else the secret of making good compass needles was in part lost, for in 1820 Peter Barlow reported to the Admiralty that 'half the compasses in the British Navy were mere lumber and ought to be destroyed'. Nor was the reliability of compasses improved when iron began to take the place of wood in the construction of ships.

It is not within the scope of this review to dilate upon the great advantages in the use of the modern system of very light needles grouped parallel to one another, which was the essence of Sir William Thomson's invention of 1876.

[1] Wilson, *Phil. Trans.*, vol. lxix.



THE COUNTESS OF WESTMORLAND'S LODESTONE

University Museum

The wonders of electricity, perhaps enhanced by the sensational demonstrations of experimenters, such as the Abbé Nollet, who in 1746 caused the discharge from a Leyden jar to pass through the bodies of a mile of monks, joined hand to hand, on one occasion, and along a line of a hundred and eighty soldiers of the Royal Guard on another, and who shortly afterwards pointed out the identity of the thunderbolts of Jove and the electric sparks of Nollet, could not but make a profound impression on the public mind. Within a few years JOHN WESLEY of Christ Church, grasping the universal utility of the new power, published *The Desideratum; or Electricity made plain and useful*, in which he describes the curative action of the electric fluid, 'the Greatest of all Remedies'. We believe that the first lightning conductors in Oxford appeared about 1770, but for exact dates we must wait for the researches of future historians in Bursary books.[1]

A notable advance was made by LORD MAHON, third EARL STANHOPE (see p. 128), who explained the phenomenon of the return stroke of an electrical discharge. His book, the *Principles of Electricity*, 1779, was translated into French in 1781.

MAGNETISM

236. Lodestone. **Before 1756.**

University Museum.

Presented by Maria, Countess of Westmorland, 1756.

The Lodestone is contained in a case resembling a coronet. Its total weight, with case and two iron poles, is 171 lb. The armature supports a weight of 163 lb., and is said to have acquired an additional lifting power of 25 lb. since it was first placed in the Ashmolean Museum. There is an engraving of it at the end of the *Catalogue of the Ashmolean Museum*, 1836.

237. Lodestone. **? 1800.**

Daubeny Collection, Magdalen College.

Weight, 3 lbs. 5 oz.; width across poles, 4 in.; lifting force, 3 lbs. 13 oz.

[1] If we may believe Pliny, both Benjamin Franklin and the Oxford Colleges were anticipated in drawing lightning down from the clouds by the Etruscans, and that Numa Pompilius was an expert in the matter.

Lodestone. **c. 1700.**

Mounted in silver. Author's collection.

Weight, 3 oz.; width across poles, $1\frac{3}{5}$ in.; lifting force, $4\frac{1}{2}$ oz.

Terrella.

Royal Society.

Sir Kenelm Digby[1] focused attention on the Terrella, by pointing out how Gilbert had by it 'compassed a wonderful designe, which was to make the whole globe

The Royal Society's Terrella.

of the earth maniable; for he found the properties of the whole earth in that little body; which he therefore called a Terrella, or little earth; and which he could manage and trye experiences upon att his will'.

Gowin Knight's Battery of Magnets. **c. 1740-50.**

No. 40, Royal Society.

Presented by Dr. John Fothergill in 1776.

It was originally constructed about the middle of the eighteenth century by Dr. Gowin Knight of Magdalen College, and was described by Fothergill in 1776. There were two magazines each containing 240 bars and weighing about 500 lbs. Each bar was 15 in. long, 1 in. wide, and $\frac{1}{2}$ in. thick, and was magnetized by the 'separate touch' method invented by Knight in 1745. Each magazine was made up of four bundles of 60 bars, the

[1] Digby, *Nature of Bodies*, 1644.

bundles being arranged end to end and the N poles of the magnets all facing the same way. Contact between the ends of the bars was secured by having end plates supplied with 60 adjustable projections, one fitting against the end of each bar.

Each magazine was mounted on a truck and capable of being easily moved about a horizontal axis.

In testing the compass needles of various makers Knight had found that the poles were anything but accurately placed. Fothergill imagines that 'a view to have such a degree of magnetic power at his command as to force the magnetic virtue through the most consolidated bars, was his first inducement to try whether he could not collect such a magazine of magnetism as would be sufficient for every purpose of this kind, and at the same time exhibit some new phenomena in physics yet undiscovered'.

The battery was used 'for the purpose of impregnating the needles he was employed to see prepared for the service of Government and others, who had generosity enough to think that the compass, on which depended the lives of the ship's crew, could not be made too perfect'.

Soon after Knight's death in 1772, the apparatus was almost completely destroyed by fire. A new one was made, however, and impregnated by Magellan, using Knight's method. It was rearranged in 1828 by Beaufort and Barlow.

In 1830 it was examined by Faraday, who found that when a cylinder of soft iron 1 ft. long by $\frac{3}{4}$ in. diameter was placed across the dissimilar poles, a force of 100 lbs. was necessary to overcome the attractive force.

[This account is taken from the official *Catalogue of the Science Collection* in the S. Kensington Museum, where the following works are quoted: 'An Account of some magnetical experiments shewed before the Royal Society, by Mr. Gowan Knight,' *Phil. Trans.*, 1744; 'Concerning the poles of magnets being variously placed,' by Dr. Gowin Knight, *Phil. Trans.*, 1745; 'An Account of the magnetical machine contrived by the late Dr. Gowin Knight, F.R.S., and presented to the Royal Society,' by Dr. Fothergill, F.R.S., *Phil. Trans.*, 1776; also *Ency. Brit.*, 8th Ed., Art. 'Magnetism'.]

The Royal Society used also to possess an 'Armed Lodestone', No. 67, a 'Piece of Loadstone', No. 80, and a 'Set of 6 bar Magnets', No. 75.

Compasses

Among the oldest compass needles in Oxford are those of the Orrery surveying instruments at Christ Church and those under some of the older globes.

The use of the compass as a surveying instrument will be again referred to under that head (p. 367).

It has been suggested that the magnetic compass may have first been applied to purposes of land surveying early in the sixteenth century.

An early form was the compass of Niccolo Tartaglia (1520-60) which was mounted in the middle of a divided circle and was furnished with a rotating alidade.

The Graphometre of Phillip Danfrie (1597), figured on p. 371, and early Plane-tables were also provided with compasses.

The dials of these surveying compasses were frequently printed with the East and West points reversed, for convenience in reading observations of compass-bearings, measured either east or west of the North-South line. An example of such a reversed dial dated 1661 is in the Evans collection. Another by Worgan is described on p. 374. The earliest instance of a reversed compass dial may be consulted in Agricola (1556).

The first prismatic compass dates from 1812. It was the invention of C. A. Schmalcalder. (E. A. Reeves.) An early example is contained in the fine collection at the Admiralty Compass Observatory, recently arranged by Capt. Creagh-Osborne, R.N.

238. Chinese Geomancer's Compass. c. 1600.

Selden Collection. Bodleian Library.

Diameter 3½ inches.

In engraved boxwood.

239-41. Three Chinese Geomancer's Compasses.

Diameters 13 inches, 9 inches, 6 inches. Pitt-Rivers.

242. Compass 7-inch needle on printed dial, in round wooden box.

Oriel College.

Made by Geo: Adams in Fleet Street, London.

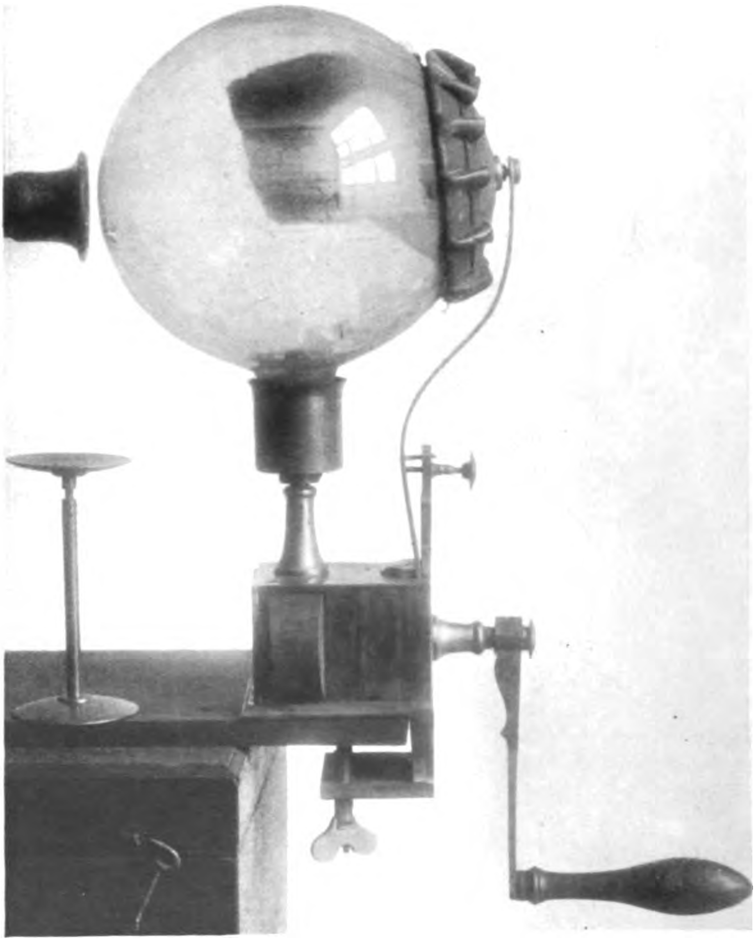
12-inch Dipping Needle. c. 1776.

Phil. Trans. 66, p. 395. No. 38, Royal Society.

By Nairne and Blunt.

FRICTIONAL ELECTRICAL MACHINE

Royal Society



NO. 243. NAIRNE'S FRICTIONAL ELECTRICAL MACHINE

Oriel College

12-inch Variation Needle.

No. 39, Royal Society.

By Jones.

ELECTRICAL APPARATUS

FRICTIONAL MACHINE

The prototype of the glass globe of the only early form of frictional electrical machine in Oxford, was the globe of sulphur that OTTO VON GUERICKE employed in his first electrical machine in 1672. In the parent machine the sulphur globe was cast in a mould, which was 'a spherical glass phial of the size of the head of an infant', which was broken when the sulphur had cooled.

The addition of the multiplying wheel arrangement was due to HAWKSBEE and others at the beginning of the eighteenth century.[1]

The rubber employed by these early experimenters to excite their spherical globes was usually the dry hand of one of the electricians, while a second, suspended by non-conducting silken cords, acted as the prime conductor as shown in the figure on the next page.

243. Vertical Spherical Frictional Electrical Machine.

c. 1760.

By Nairne, London. Oriel College.

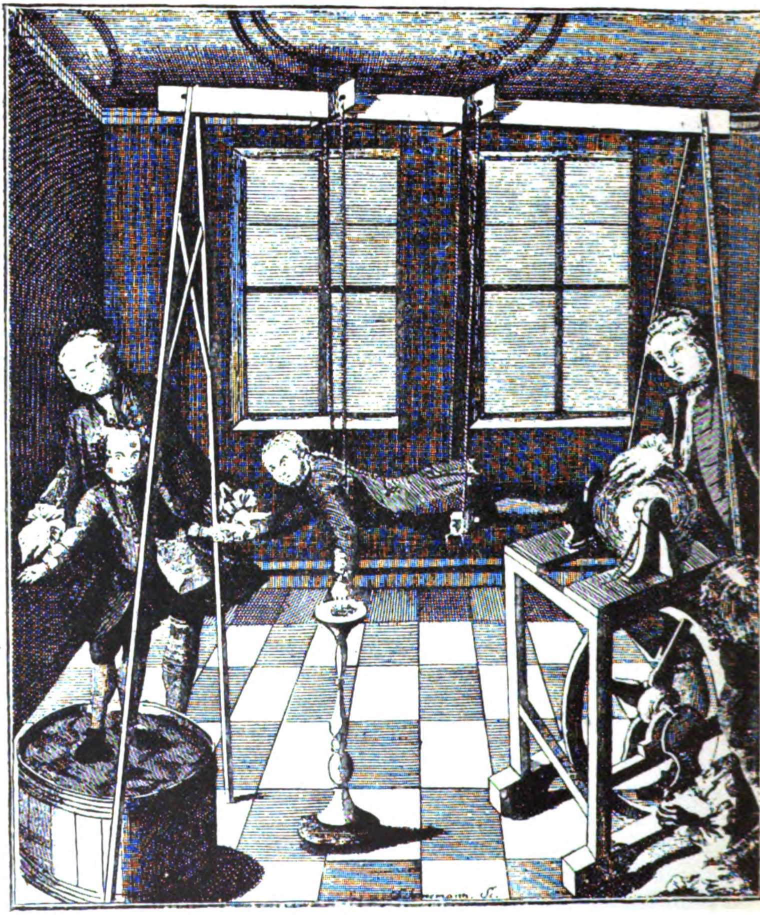
A Vertical Globe Machine was first made by Leupold of Leipzig.

In this compact machine the neck of a 9-inch glass globe (cracked) is cemented to the upper end of a vertical axis which is rotated by means of a crank handle, with cogwheel and tangent-screw gear contained in a brass box, the machine being secured to a table by means of a clamp. The rubber is supported by a brass spring, and its pressure is adjustable by means of a screw. The prime conductor, insulated by

[1] F. Hawksbee, *Physico-Mechanical Experiments on various subjects; containing an account of several surprizing Phenomena touching Light & Electricity, producible on the Attrition of Bodies.* London, 1709. Rees' *Cyclopaedia, Electrical Machine,* Fig. 6, Pl. VIII; Priestley, *Hist. of Electricity,* 2nd edit., 1769, p. 498; Chambers' *Encyclopaedia,* 1786–9.

a glass pillar, is supported by a separate stand, and is provided with a Lane's discharging electrometer.

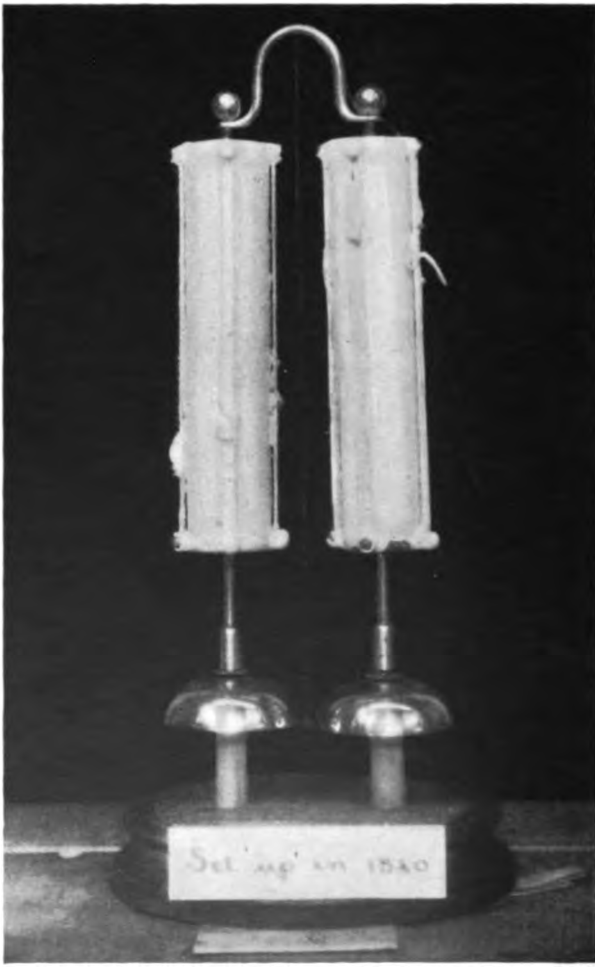
The machine and accessory apparatus, prime con-



THE PRODUCTION OF ELECTRICITY BY FRICTION, 1743.
Hausen, Novi Profectus in Hist. Electricitatis.

ductor, brass plates, bells, and dancing figures are contained in an oak box.

The Plate Machine was constructed by Jesse Ramsden, *c.* 1770.



NO. 244. ZAMBONI DRY-PILE, 1840

Clarendon Laboratory

244. Zamboni Dry-Pile. **1842.**

Clarendon Laboratory.

The invention of G. Zamboni of Verona in 1812.

This battery has acquired a world-wide celebrity, from being described in Silvanus Thompson's *Electricity*. The poles are two metal bells, and between them is hung a small brass ball, which, by oscillating to and fro, slowly discharges the electrification. Save for slight interruptions when moved it has now been continuously ringing the bells for more than 80 years.

245. Torsion Balance Electrometer below a brass chamber with glass window.

Radcliffe Observatory.

By ? Palmieri.

This instrument was probably used to demonstrate atmospheric electricity. Instruments for showing the presence of electric states of the atmosphere have been known for a long period to Mediterranean sailors.

At the Castle of Duino, in Fiume, on the Adriatic, there used to be a pointed rod fixed in a vertical position on one of the bastions. Bianchini states that such a bar has been used from time immemorial to give warning of an approaching storm.

'In summer, when the weather has the appearance of being stormy, the soldier who mounts guard in his bastion examines, or tests the iron rod, by presenting to it the point of an iron halbert (always ready for this purpose), and whenever he perceives that the iron rod gives out sparks, or shows a small germ of flame at its point, he rings a bell, to give notice to the country people working in the fields, or to the fishermen at sea, that stormy weather is approaching.

'This custom is of great antiquity. It is mentioned by Imperati in a letter dated 1602.' Fitzroy, *Weather Book*, p. 460.

Atmospheric electricity had been the subject of special study by Andrew Crosse (1784–1855) of Brasenose College, who lived at Fyne Court in Somerset. He used long horizontal wires attached to glass pillars.

Nails fused together by lightning. c. 1770.

No. 362, Ashmolean Museum.

Presented by Dr. Hornsby.

The fusion occurred during the time of the building of the Radcliffe Observatory.

The Daubeny Electrical Apparatus. 1800–50.

Magdalen College.

Dr. Daubeny bequeathed a considerable number of pieces of early electrical apparatus to Magdalen College for preservation in the Laboratory which he had built, and some instruments of historic interest are still there. All the early types of voltaic cells, the frictional machines of about 1850, and many other pieces of accessory apparatus were well represented. The author when College tutor in Natural Science had the privilege of saving (for a short time) many fragments from the corroding fumes of a chemical laboratory. The greater part of the apparatus is, however, figured in many a text-book, and consequently does not need special description here.

METEOROLOGY

Weather Records

We may fairly claim that the art of keeping scientific Records of the Weather had its birth in Oxford.

William Merle, Fellow of Merton, admitted Rector of Driby, co. Lincs., 1331, and died 1347, has the high distinction of being the first man in the world to keep a journal of the weather. His *Consideraciones temperiei pro 7 annis*, 1337-44, has been reproduced in facsimile by G. J. Symons in 1891.

Merle was also the author of useful *Regule ad futuram aeris temperiem pronosticandam.* Both MSS. are in the Bodleian Library in MS. Digby 176.

The same volume contains various writings by William Rede, Bishop of Chichester, *c.* 1365, and will be mentioned again in our account of him. It also contains an *Almanak solis pro 4^or annis per W. Reed Anno Christi 1337° calculata et scripta*, and three early treatises of interest to meteorologists, Plinius, *de Temporibus*, Alkyndyus, *de Ymbribus*, and a *Tractatus de Pluviis*.

The tract by Alkindus is an early MS. of part of his work *De Temporum mutationibus*, written by him about A.D. 1100, and printed at Venice in 1507 with the title *De Pluviis Imbribus et Ventis, ac Aeris mutatione.*

The following entries, selected from many hundreds, will give some idea of the style of Merle's record:

A.D. 1337. In **January** there was warmth, with moderate dryness, and in the previous winter there had not been any considerable cold or humidity, but more dryness and warmth.

In **May** four days were humid, with moderate warmth. All the remainder was moderately warm and dry, with moderate showers at intervals, but on the 17th there was sudden heavy rain, with thunder, heavier than any that had fallen at Oxford in so short a time for many years.

A.D. 1340. In **July** the first week was windy. On the 1st day there was a strong wind, and on the 3rd stronger than on the 1st, with very light showers occasionally, but not

sufficient to hinder in the least the workers in the hay-fields. On the 7th and six following days there was heavy rain which hindered the workers in the hay-fields very much, and penetrated the earth considerably, but not so much as the rain which fell in May; and it was heaviest on the 17th. There was moderate wind on the 15th, lasting for the five following days, which was very strong on the 18th and 19th. On the 16th and four following days, light rain. On the 22nd, 23rd, and 24th, great heat. On the 25th, 26th and 27th, great heat directly after midday. 28th, light wind. 30th and 31st, very strong wind. 29th, 30th and 31st, light rain.

A.D. 1342. June. 1st, rain, with rather strong W. wind. 2nd, light rain. 3rd, fog. 5th and 6th, considerable heat. 10th and 11th, rather strong N.W. wind. 7th, 8th, 9th, and 10th, rain. 12th, 13th, 14th, 15th, rain. 16th, very heavy rain, which, by its own power, together with that of the preceding rains, penetrated considerably. 17th and 18th, light rain. 19th, moderate rain at Oxford; but there was extremely heavy rain in certain parts at a distance of seven English leagues from Oxford. 20th, heavy rain with severe hail and thunder at Oxford, but in certain parts, at six leagues distance, there was not much rain. 24th, heavy rain, with much thunder and lightning. 25th, rain. Last day, light rain.

December. 6th, rain. 8th, frost, with ice. 15th, rain. 14th, light rain. 22nd, fog. 27th, rain. On the last three days, hard frost. Many times in this month there was fog, and occasionally light rain when not mentioned here. 21st, there was slight frost on the grass, but on the following morning it was not visible.

It is to be noted that there was dryness about April this year, as there was in the years of Christ, 1333 and 1340.

It is also to be noted that there was spring-like weather the whole time between September and the end of December, except on those days to which frost is ascribed, so much so that in certain places the leeks burst forth into seed, and in certain places the cabbages blossomed.

A.D. 1343. March. . . . 28th, stormy, with very strong N.W. wind, and with hail, rain, and snow very often in the day. At mid-day there was an earthquake, which was so great that in certain parts of Lyndesay (in Lincolnshire) the stones in the chimneys fell down, after shaking in very great agitation, and it lasted long enough for the 'salutatio angelica' to be said distinctly. 29th, stormy, with hail, snow, frost, rain, and N.W. wind. . . . The aforementioned earthquake was not felt at Oxford.

September. . . . In this month loud complaint arose on account of the scarcity of wind. In the second week a burning dragon [= comet] was seen about sunset, or before, in Lyndesay, which betokened future dryness then.

A.D. 1344. January. 1st and three following days, frost, with thin ice. 5th, thaw, with fog. 6th, light rain, as light as possible. 8th, very strong W. wind. 10th.

[The record breaks off abruptly here.]

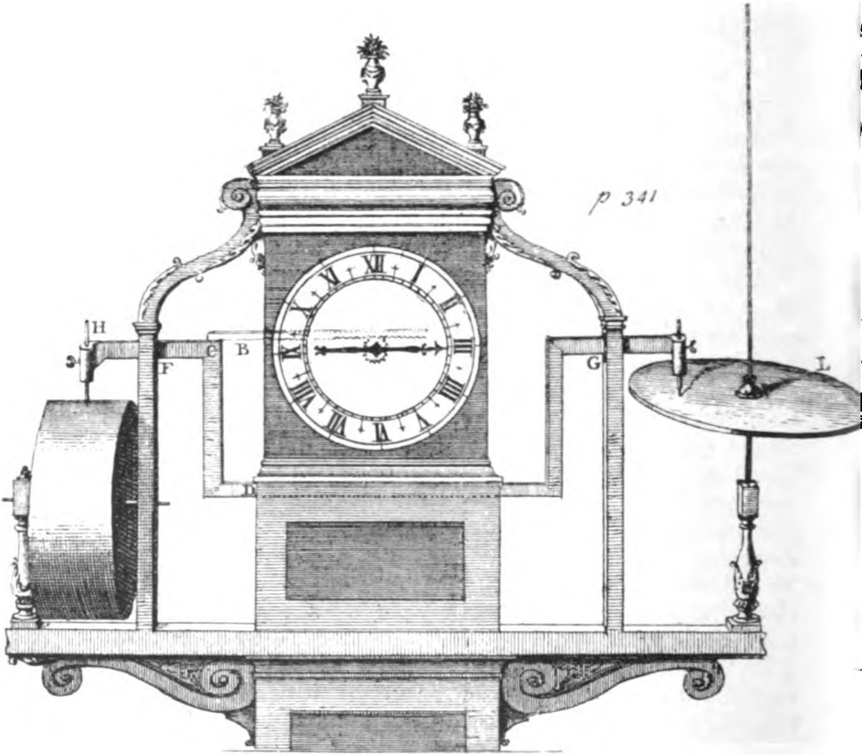
There are two other treatises by Merle in the Bodleian. *Notula Magistri Merle de futura temperie aeris pronosticanda* is in MS. Digby 97, and *Tractatus de pronosticacione aeris secundum Willelmum Merlee*, dated Oxon. anno Domini 1340, is in MS. Digby 147; but, as Symons has pointed out, in the matter of weather prognostication Merle was preceded by Aristotle, Aratus, and Virgil. It is as a keeper of a day-by-day record of the weather that he is pre-eminent.

After a lapse of more than three hundred years Sir CHRISTOPHER WREN recommended the Royal Society to direct its energies to a punctual diary on meteorology, and to study the effect of the weather upon medicine: 'Instead of the vanity of prognosticating he could wish we would have the patience for some years of registering past times which is the certain way of learning to prognosticate.' According to Wren, a **Diary of Wind and Weather** should include entries as to heats and colds, drought and moisture, and weight of the air through the whole year, 'this in order to the *History of Seasons*: with observation, which are the most healthful or contagious to men or beasts; which the harbingers of blights, meldews, smut, or any other accidents attending men cattle or grain; so that at length being instructed in the causes of these evils, we may the easier prevent, or find remedies for them'.

'To facilitate the constant observation of temperature and wind, Wren contrived a self-registering thermometer and an automatic wind recorder. He annexed a clock to a weather cock, which moved a rundle covered with white paper; upon which the clock moving a black-lead pencil, the observer, by the traces of the pencil on the paper, may certainly know what winds have blown, during his sleep or absence, for 12 hours together.'

This self-registering weather clock was suggested at a Meeting of the Royal Society on Dec. 9, 1663. It was improved by Robert Hooke in 1664. The clock was driven by a 75-pound weight.

We have here an early suggestion of the value of an



WREN'S WEATHER CLOCK, 1663.

automatic tracing or graph, such as is employed in most self-recording machines nowadays. In Wren's description, he says 'On both surfaces are described circular lines for the hours, according to the motion of the rack, and cross to them strait lines, shewing degrees of weather in the one, and rumbs in the other: amongst these permanent lines the pencils describe irregular lines, compounded of the motions of the rack and and wheels, much

like the motion of the ship described among the longitudes and latitudes of the chart: and from these tracks of the pencils may be collected the changes of wind and weather, that have been in the twelve hours last past.'

'These surfaces may be printed papers slightly stuck on with mouth-glew, using bread to efface the old tracks. Or they may be a proper ground of whiting, into which the durable lines are stained; the other being to be wiped out with a sponge. Or they may be box or ivory, or unburnished silver; if the lines engraven be so filled, that the pencils stick not in them to hinder the motion.'

This machine of Wren's has produced an illustrious progeny. Even the phonograph and gramophone may be regarded as its descendants.

Wren also discovered 'many subtile ways for easier finding the degrees of drought, and moisture, and the gravity of the Atmosphere; and amongst other instruments, has Ballances (also useful for other purposes) that shew the pressure of the air, by their easie (I had almost said spontaneous) inclinations'. (Plot.)

At about the same time both HOOKE and BOYLE provided instruments which are essential to the meteorologist, and with them made the preliminary observations, that were needed to convince the scientific public of their value. Of capital importance are Boyle's *History of Cold*, 1665, to which reference has already been made on p. 262, his *Observations and Directions about a Barometer*,[1] published on April 2, 1666, and his *General History of the Air*.

Daily barometric observations were made by Dr. JOHN WALLIS with Boyle's barometer 'for about six years together: in all which time he found the quick-silver in the tube never to ascend much above 30 inches, and never to descend much below 28'—a platitude now, but then a new and perhaps unexpected discovery.

From June 24, 1666, to March 28, 1667, and from March 14, 1681, to December 1682, and in the last ten days of June 1683, a *Register* of the Temperature, Atmospheric Pressure, Moisture, Wind, and Weather was kept in Oxford by JOHN LOCKE.

The instruments used comprised a sealed thermoscope

[1] *Phil. Trans.*, No. xi, p. 181.

of uncertain scale, a mercurial barometer, and a hydroscope made of the beard of a wild oat.

One entry is of such exceptional interest that the recorder has added an explanatory note.

1666. *September 4*, Wind E. *Weather*, Dim reddish Sunshine.

'This unusual colour of the air, which, without a cloud appearing, made the sunbeams of a strange dim red light, was very remarkable. We had then heard nothing of the fire of London: but it appeared afterwards to be the smoke of London then burning, which driven this way by an easterly wind caused this odd phenomenon.'

The note on March 8, 1667, is 'Very hard frost, *Thames* frozen; carts went over'.

ROBERT HOOKE's contributions to the list of Meteorological Instruments included the Wheel Barometer, the Double Barometer, the Marine Barometer, 1700 (*Phil. Trans.* xxii. 791), and an Anemometer (*Phil. Trans.* ii. 444) of a form lately recommended for universal use by Professor Wild. (Scott, *Meteorology*, p. 150.)

RADCLIFFE OBSERVATORY

A **Meteorological Observatory** of the first class was built by the Radcliffe Trustees in 1772. The octagon top, surmounted by a globe, so familiar in many views of Oxford, was designed from the Temple of the Winds. The bronze figures on the eight sides of the tower, representing the winds, were copied from the designs in Stuart's *Athens*, and were executed by Bacon.

BAROMETER

See also p. 243.

The opinion of Descartes, that the variations of the barometer were caused by the action of the moon, was tested experimentally about 1647 at the instance of Pascal, at a place near Clermont in France. Similar observations in Oxford were made by WREN before he left for London in 1657,[1] and with such fruitful result that the practical use of the instrument as connected with the weather was attributed to Wren, and was so recorded at a Meeting of the Royal Society in February

[1] Boyle, *Works*, i. 41; Ward, *Lives*, p. 97.

1679.[1] BOYLE's observations have already been referred to on p. 244. HOOKE was also acquainted with the relation of barometrical readings to changes in the weather. His wheel barometer was an important invention.

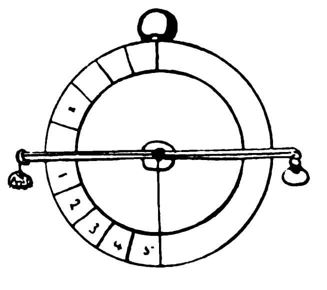
247. Barometer. 1838.

Radcliffe Observatory.

By Newman. 0·528 inch tube. The Readings were found to be identical with those of the barometer at the Royal Society (*Radcliffe Astron. Observ.* 1840).

HYGROMETERS

An early form of Hygrometer was designed by Leonardo da Vinci, *c.* 1500, and is figured in the *Cod. atl.*, pl. 249ᵛ. In this instrument a weight counterpoises a hygroscopic piece of sea-sponge which varies in weight according to the wetness or dryness of the air.



Hooke's Hygroscope made of the beard of a wild oat was devised in July 1663.

Goddard's Hygroscope was a 'contrivance of a lute string with pullies and a cylinder'. It was brought to the notice of the Royal Society on 7 Oct. 1663.

An improvement to an Hygroscope made of two boards of deal, or rather of poplar,[2] was contrived by JOHN YOUNG of Magdalen Hall. In this instrument 'the teeth of the thin piece of brass placed across the juncture of the two boards, must needs in its passage from bearing on one side of the teeth of the pinion, to the other, upon change of weather, make a stand as it were in respect of the motion of the axel of the hand; . . . a pretty stiff spring cut on the under side, after

[1] See Derham's account of Hooke's experiments published in 1726 (*D. N. B.*).

[2] *Phil. Trans.*, No. 127.

the manner of a fine file, placed flat and not edge-ways, and bearing pretty hard upon an axel of copper, may turn the hand upon change of weather in the punctum of reversion, without any more than a negative rest'. (Plot, p. 230.)

248. Daniell's Hygrometer. **1878.**
University Observatory.

By Bouillard.

Captain Kater's Hygrometer. **1809.**
Royal Society.

By Robinson. Cf. *Asiatic Researches*, ix.

Daniell's Hygrometer. **c. 1823.**
Royal Society.

By Newman.

Daniell, *Meteorological Essays*.

Jones's Hygrometer. **1826.**
Royal Society.

With stem bent at right angles.
Phil. Trans. 1826.

Jones's Hygrometer.
Royal Society.

With stem bent at an acute angle.
Phil. Trans. 1826.

Rain-Gauges

It is generally assumed that simple inventions precede the complex, but in the case of rain-gauges the order was inverted, and the first British Rain-gauge was a self-recording one.

Wren's self-emptying Rain-gauge was so arranged that it 'measures the quantity of Rain that falls, which as soon as 'tis full, empties it self, so that at the years end 'tis easie to compute how much has fallen on such a quantity of ground for all that time; and this he contrived in order to the discovery of the Theory of Springs' (Plot). Wren demonstrated the principle to the Royal Society on January 22, 1662.

It was described by Grew as a 'triangular Tin-vessel hanging in a frame, as a bell, with one angle lowermost.

From whence one side rises up perpendicular, the other sloped; whereby the water, as it fills, spreads only on one side from the centre, till at length it fills and empties itself. Which being done, a leaden poise, on the other side, immediately pulls it back to fill again.' It was in the Museum of the Royal Society in 1683.

Pluviometer. **1695.**

The invention of Robert Hooke, in which the water was *weighed*.

This rain-gauge consisted of a large glass bottle holding more than two gallons and having a neck 20 inches long. The funnel too was made of glass, and was 11·4 inches in diameter, the whole being fixed in a wooden stand, something like an old-fashioned jelly-stand. The funnel was steadied by two pack-threads attached to the frame by pins and passing over the edge of the funnel. The amount of water collected was carefully weighed every Monday morning, and it was found that between August 12, 1695, and the same date in 1696, using troy weight, the rainfall in the interval weighed 131 lb. 7 oz. 113 grs., equivalent to 29·11 inches.

249. Rain-Gauge.

Radcliffe Observatory.[1]

Circle 1 ft. in diam.; top is 22 ft. 9 in. from ground; pipe 32 ft. due E. of Tower; Glass Measure is a cylinder 1 in. in diam.; so that 1 in. = 0·00627 in. of rain on the top.

Wind Vane and Dials. **1676.**

On the top of the Mount in the Garden of New College.[2]

The dials were constructed on a pile of books with Time on the top, exactly pointing out from what quarter the wind blows, upon the 32 points of the compass, depicted on a cylinder of stone. This ingenious contrivance has been removed.

Wind Vane. **1682.**

Tom Tower, Christ Church.

By Chr. Wren.

Described in a letter to Bishop Fell.

[1] On Dec. 31, 1774, P. and J. Dollond supplied a copper funnel for a Pluviometer for £2 12*s.* 6*d.*

[2] Plot, c. 9, p. 141.

Anemometer. **16—.**

Invented by Robert Hooke (*Phil. Trans.* ii. 444). This form has lately been recommended for universal use by Professor Wild (Scott, *Meteorology*, 150).

Dr. Lind's Portable Wind-Gauge. **1775.**
Royal Society.

Phil. Trans. lxv, p. 353.

Weathercocks.

A correspondent of the *Oxford Magazine* of May 17, 1918, contributed an illuminating note upon the behaviour of the weathercocks of Oxford. The uncertainty that he deplores is not unknown in other cases in which later and less scientific generations have attempted to avail themselves of the instruments of an earlier age.

'Are weathercocks for ornament or for use? If the latter, could their owners take some measures to ensure consistency? On one morning last week the weathercock at Exeter College pointed due North, to which quarter that cock is almost as faithful as the Pole Star, while Balliol with charming inconsistency had one bird pointing NE. and another pointing SW. The same afternoon three weathercocks at Trinity, on closely adjoining gables, pointed NE., NW., and SW. The only parallel to such uncertainty is the well-known divergence of the four weathercocks at St. Sepulchre's, London, where each maintains its own quarter.'

221. Ronald's Photo-meteorological Instrument. **1854.**
Radcliffe Observatory.

This instrument was replaced by another, after working continuously until 1878. *See* p. 283.

251. Campbell's globular lens for Sunshine Records. **1878.**
University Observatory.

Storm Glass or **Camphor Glass.** **c. 1590.**

The inventor of Storm Glasses has now been forgotten; later on they were sold on old London Bridge, at the sign of the *Looking Glass*, *c.* 1750.

They contain a mixture of camphor, nitrate of potassium, and ammonium chloride partly dissolved by alcohol, with water, and some air in hermetically sealed glass tubes. Fitzroy, *Weather Book*, p. 445.

SURVEYING INSTRUMENTS

In the year 1619, Sir Henry Savile, Knt., observing that the Study of Mathematicks was very much neglected; and being desirous to apply a Remedy thereunto, lest that the same should wholly decay; by Royal Authority . . . founded and endow'd for ever two public Lectures; the one in Geometry and the other in Astronomy. The Professor of Geometry is properly to read on the 13 Books of Euclid's *Elements* . . . and all Archimedes's Books. . . . It is moreover the Duty of this Professor to teach and explain . . . Practical Geometry, or Measuring of Land, at a proper season most convenient for him.

J. Ayliffe, *Ancient and Present State of the University of Oxford.* 1714.

MEASURES OF LENGTH

MEASURES of distance, height, and depth were universally made by primitive peoples by direct comparison with arbitrary units of length chosen from parts of the human body. We still retain the names of several of these natural units of length, e.g. the foot, the fathom, the span, the cubit, &c., and the Roman 'passus' is hardly less anatomical in origin. In the Oxford Collections there is a good example of an ancient standard fathom and foot from the island of Samos. (Cf. p. 163.)

In early days long distances were measured by pacing, a method that was employed by the *Bematists* who accompanied Alexander the Great on his campaigns; and the unit of length, the 'stadion' of 200 steps or 600 Greek feet, was evidently derived from the same practice.

For the measurement of the long distances necessary for estimating the length of a degree, a carriage wheel was employed by Jean Fernel (1497–1558), who thus re-adapted the principle of the Greek Hodometer, an arrangement of cogwheels and endless screws on the same axes, working in the teeth of the next wheels, as described in Heron's *Dioptra*.

The saying, that 'there is nothing new under the sun', is partially illustrated by the invention of **Waywisers,** as early **Taximeters** were called. The first record of them occurs in the *Diary* of John Evelyn. On August 6, 1656,

'I went to see Colonel [Thomas] Blount, who showed me the application of the "Waywiser" to a coach, exactly measuring the miles and showing them by an index as we went along. It had three circles, one pointing to the number of rods, another to the miles, by 10 to 1,000, with all the subdivisions of quarters; very pretty and useful.'

WREN's researches on this machine have been referred to on p. 213.

Wilkins's Way-Wiser. **c. 1678.**

Formerly in the Museum of the Royal Society.

''Tis very manageable. It hath five *Indexes* pointing to so many different Measures, *sc.* Perches, Furlongs, Miles, Tens of Miles and Hundreds of Miles; and turn'd about with as many wheels. Made to work in a *Coach*, thus; In the middle of the axletree is cut a little box to receive the Wiser: from whence the axletree is made hollow to the end. In this hollow lies a rod, loose from the axletree, and fastened at one end to the nave of the wheel, and so turns round with it. And with a *Worm* it hath at the other end, at the same time, it turns the *Perch Wheel* of the Wiser, and that all the rest. Yet by this measure, 1 yard will sometimes be lost in a 100 yards.' Grew, *Catalogue*, 1681, p. 360.

One of the principal modern units of length employed by land surveyors is associated with the name of an Oxford man, EDMUND GUNTER, a member of Christ Church in 1600, and afterwards Gresham Professor of Mathematics in London. His chain was preceded by the 'Wyer Line' of Cyprian Lucar, 1590, figured on p. 373.

73. Gunter's Chain. **Invented c. 1620.**

Of 100 links, making 66 feet. Christ Church.

There is every reason to believe that this is an early example of the Chain devised by Edmund Gunter, and there is an especial appropriateness in its being preserved in the College of which he was so distinguished a member.

INSTRUMENTS FOR DETERMINATION OF STANDARD DIRECTION

THE VERTICAL

The Plumb Line

From time immemorial the true vertical has been obtained by the use of a plumb line. As soon as builders began to desire to test their columns and walls for verticality, a string and a stone would have provided them with an instrument capable of more reliable results than mere inspection 'by eye'.

No doubt in time bronze superseded stone as a bob, and eventually in Roman hands lead took the place of both and gave its Latin name *plumbum* to the verb 'to plumb', meaning to test verticality. Finally, in modern instruments of precision, brass has taken the place of lead.

THE HORIZONTAL

The Plumb Level

By the addition of a T-square to the plumb line, the horizontal direction could be obtained; and the same result was commonly obtained by the suspension of the plumb line from the apex of an isosceles triangle, usually either a right-angled or equilateral triangle. The latter scheme was adopted by Leonardo of Pisa[1] in 1220 for his 'Archipendulum', a massive equilateral triangle with a cord fixed to the apex, from which hung a plumb-bob —a very 'necessary apparatus for surveying'.

Clinometer. 1554.

Brass, gilt. Bodleian Library.

A miniature clinometer is included in the metal pocket dial 'book' of instruments and tables described on p. 127 of vol. ii.

252. Plumb Level and Clinometer. c. 1579.

Bodleian Library.

Brass gilt and engraved with Arabesque ornamentation. With pin-hole sights. 9½ inches wide.

Probably presented by Josias Bodley with the Schissler

[1] *Practica Geometriae.*

geometer's quadrate stated to have come into the Library in 1613.[1] One oak box fits both instruments.

The plummet (missing) was hung in the centre of an arc of 5½-inch radius, graduated to 90° on each side of the normal. The two sights are hinged for packing.

Although this instrument does not appear to have been made by the same hand as the Schissler Quadrate, it was probably used in connexion with it, for the oak quadrate-case which appears to date from the seventeenth century is recessed for its reception.

Gunners' Levels.

We have not found in Oxford a single example of the quadrantal clinometers that were very widely used *in arte bombardica* in the sixteenth and seventeenth centuries. Robert Fludd (1617)[2] of St. John's gives a picture of one with the quadrant divided into 12 parts, in contradistinction to the 90 parts of the Astronomer's quadrant. There are several choice examples of gunners' levels in the L. Evans collection, which well illustrate the various types of the instrument, and the work of 'C. T.' (? Christof Tressler) 1616, Georg Zorn 1624, 'F. F. F.' 1629. French makers were Butterfield and Picart of Cambrai *c.* 1710–40.

Levels

Wren's Bowl Level. 1666.

An exceedingly simple form of level was described by Sir R. Moray to the Royal Society on 5 Dec. 1666.

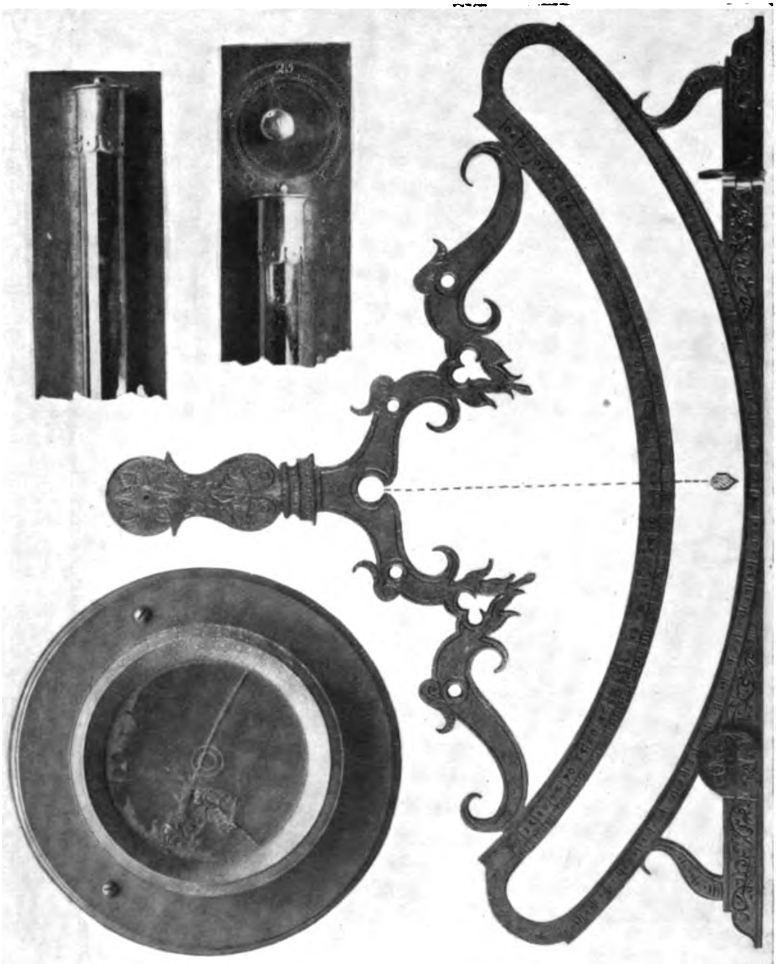
It was 'for taking the horizon every way in a circle'. It consisted of a bowl, with an accurately turned lip. It was mounted on a ball-and-socket joint, so that when a drop of quicksilver was adjusted to the centre, the lip should lie level in every direction. Wren had probably found the want of some such instrument in his survey of London after the great fire. Distant objects were sighted by a 'dioptra' laid upon the edges of the bowl, which was made of glass. (14 March 1666–7.)

Bubble Levels

Water levels had been used by surveyors ever since the days of Vitruvius (63 B.C.–A.D. 14) who described

[1] Bodleian Library copy of Macray's *Annals of the Bodleian.*

[2] Fludd, *Macrocosmos*, p. 405.



NOS. 253 AND 254. LORD ORRERY'S BUBBLE LEVELS, C. 1700

Christ Church

NO. 252. PLUMB-LEVEL AND CLINOMETER, C. 1579

Bodleian Library

both 'libra aquaria' and 'chorobates'. In more modern form they were used by Picard (1620-82), Huygens (1629-95), de la Hire (1704), and Römer (1644-1710), but the more compact water tube level did not come into existence before the second half of the seventeenth century. It was the invention of Melchisedech Thevenot. Both tube and circular bubble levels are represented in the Orrery Collection, in Christ Church, and there are probably not many, if any, levels of the circular pattern now in existence, which are older than the Oxford instrument. It is said that spirit was first used in 1775 by Felice Fontana (1730–1805).

Hooke's Level. **28 Nov. 1666.**

'Mr. Hooke produced a new kind of level, by including a large bubble of air in a glass-pipe, having its sides exactly blown, and filled with water, and sealed up at both ends.' (Birch, *Hist. Royal Society*, ii, p. 128.) We have no specimen of the work of this member of the House in Oxford.

253. Water tube Level. **c. 1700.**

9 inch, with micrometer screw. Orrery Collection 31.

The base plate is supported on two bosses at one end and by the point of the micrometer screw at the other. Two similar triangles are engraved on the plate, the sides of the one marked 8 and 150 being exactly $\frac{1}{3}$ the length of those of the other marked 24 and 450.

The fluid is coloured pink.

254. Circular bubble Level. **c. 1700.**

Diameter of glass $2\frac{1}{2}$ inches. Orrery Collection 36.

Mounted on a base plate 5 in. diam. by 3 adjusting screws. The centre of the top glass (now cracked) is marked by two concentric rings.

This we believe to be the earliest example of a circular bubble level in existence; and though not marked with the name of any maker, it is in all probability the work of John Rowley, who may, provisionally, be regarded as the inventor of this type of level. The view that Rowley was the first maker of such levels is supported by information given me by Mr. G. Gabb, that he has

seen a universal sundial, made for the Duke of Chandos by Rowley, in which a circular level was introduced.

Telescopic Levels

Levelling Instrument with telescope. **1703.**

Trinity College, Cambridge.

Marked: I. Rowley Fecit.

A 6-in. tube-level mounted on the top of a $11\frac{3}{4}$-inch telescope, with cross-wires.

This, the oldest telescopic level that we have seen, is associated with a protractor by the same maker and an astronomical ring-dial by John England, also dated 1703. It belonged to Sir Isaac Newton, and is marked with the year when he became President of the Royal Society.

Level for Halley's Meridian Telescope. **1722.**

A hanging level: see vol. ii, p. 305.

In the hands of Cary and Troughton & Simms the Level, combined with telescopes, became an instrument of great precision. An instrument by the former maker was used by Lloyd for a survey of the Thames,[1] and is in the possession of the Royal Society. At least one specimen of Troughton's later work is in Oxford.

255. Troughton's Improved Level. **c. 1834.**

Univ. Observatory.

Telescope: aperture $1\frac{1}{4}$ in. and 16 in. focal length.

ANCIENT SURVEYING INSTRUMENTS

When questions of relative position had to be decided and described, more elaborate surveying instruments became necessary; and in their construction the first geographers worked along lines almost identical with those with which astronomers have long been familiar.

The earliest instrument of all, the **Gnomon,** a simple upright rod, known to the Chaldeans as an instrument for measuring time, was certainly one of the oldest of the simple survey instruments, for by measurement of the length of its shadow along a horizontal surface, latitudes or distances from the equator could be calcu-

[1] *Phil. Trans.*, 1831, p. 167.

lated. The gnomon was introduced into Greece from Babylon by Anaximander (611–*c.* 547 B.C.).

Occasionally remarkably accurate determinations of latitude were made by the ancients by the use of a gnomon. Pytheas, about 326 B.C., in preparation for a voyage of discovery which ended in the finding of our island of Britain, sailed from Phocaea to Marseilles. There he erected a large gnomon divided into 120 parts, and fixed its latitude with a result that seems almost incredibly accurate, for, adding the sun's semi-diameter which he omitted, the latitude he obtained differs not more than one minute from the true latitude of Marseilles Observatory.

From the simple gnomon Aristarchus (310–230 B.C.) contrived the first type of instrument with a divided circle for measuring angles. He saw that if an upright rod is mounted in the middle of a hemispherical bowl, and is made equal in length to the radius of the bowl the position of its shadow at noon might be made to give the latitude directly without calculation. For this purpose the interior of the bowl was marked with a scale of concentric equidistant circles. (See figure in vol. ii, p. 16.)

This instrument was called a **Scaph.** It may have been also used by Aristarchus for his determination of the apparent diameter of the sun as $\frac{1}{720}$th of the Zodiac circle.

The **Diopter** was an instrument used by early land-surveyors for marking off similar angles. It is described in a treatise by Hero of Alexandria (third century A.D.) and was used to settle (*a*) problems of 'heights and distances', (*b*) engineering problems, (*c*) problems of mensuration.

To determine the difference of level between two given points.
To draw a straight line connecting two points, the one of which is not visible from the other.
To measure the least breadth of a river.
 ,, the distance of two inaccessible points.
 ,, the height of an inaccessible point.
To determine the difference between the heights of two inaccessible points and the position of the straight line joining them.
To measure the depth of a ditch.
To bore a tunnel through a mountain going straight from one mouth to the other.

To sink a shaft through a mountain perpendicularly to a canal flowing underneath.

Given a subterranean canal of any form, to find on the ground above a point from which a vertical shaft must be sunk in order to reach a given point on the canal (for the purpose, e. g., of removing an obstruction).

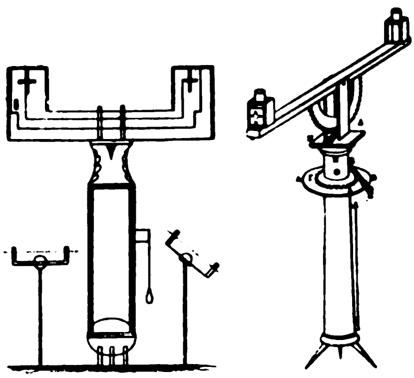
To construct a harbour on the model of a given segment of a circle, given the ends.

To construct a vault so that it may have a spherical surface modelled on a given segment.

Given that all the boundary stones of a given area have disappeared except two or three, but that the plan of the area is forthcoming, to determine the position of the lost boundary stones.[1]

To measure a given area without entering it, whether because it is thickly covered with trees, obstructed by houses, or entry is forbidden![2]

Colonel Laussedat[3] has attempted a reconstruction of the diopter which is here reproduced. A bar with



THE DIOPTER.
Laussedat, Recherches sur les Instruments.

sights appears to have been mounted on trunnions at the top of a rotatable vertical axis. The stand was mounted upon a tripod and was adjusted in a vertical

[1] It has been suggested that this problem, not an uncommon one in Egypt when the Nile flood had destroyed the landmarks, was one of the very problems which geometry was intended to solve. (Heath, *Greek Mathematics*, ii, p. 307.)

[2] Hero, περὶ διόπτρας. (*Heronis Opera*, iii, Teubner, 1903.)

[3] *Recherches sur les Instruments.*

position by means of a plumb line. The movements in azimuth and in altitude were probably effected by tangent screws engaging in cogwheels.

There is no mention of any addition of special graduated circles, but then the teeth of the cogwheels would have afforded a ready means of setting the instrument. With the addition of graduated circles the diopter would have become a theodolite.

We now come to the instrument which has a domestic interest to us, because by it the latitude of Oxford is first known to have been determined. The **Astrolabe**

SURVEYORS MEASURING HEIGHTS BY SHADOWS AND ASTROLABES.
MS. Canon. Misc. 340.

was a compendium of instruments which included a rotatable rule or alidade carrying sight vanes, the position of which could be read by a circle of degrees around the rim of a heavy circular plate which was hung from the thumb of the observer in a vertical plane during an observation. The altitude of the sun was readily obtained by adjusting the rule so that a ray of the sun should traverse two pin-holes in the sight vanes.

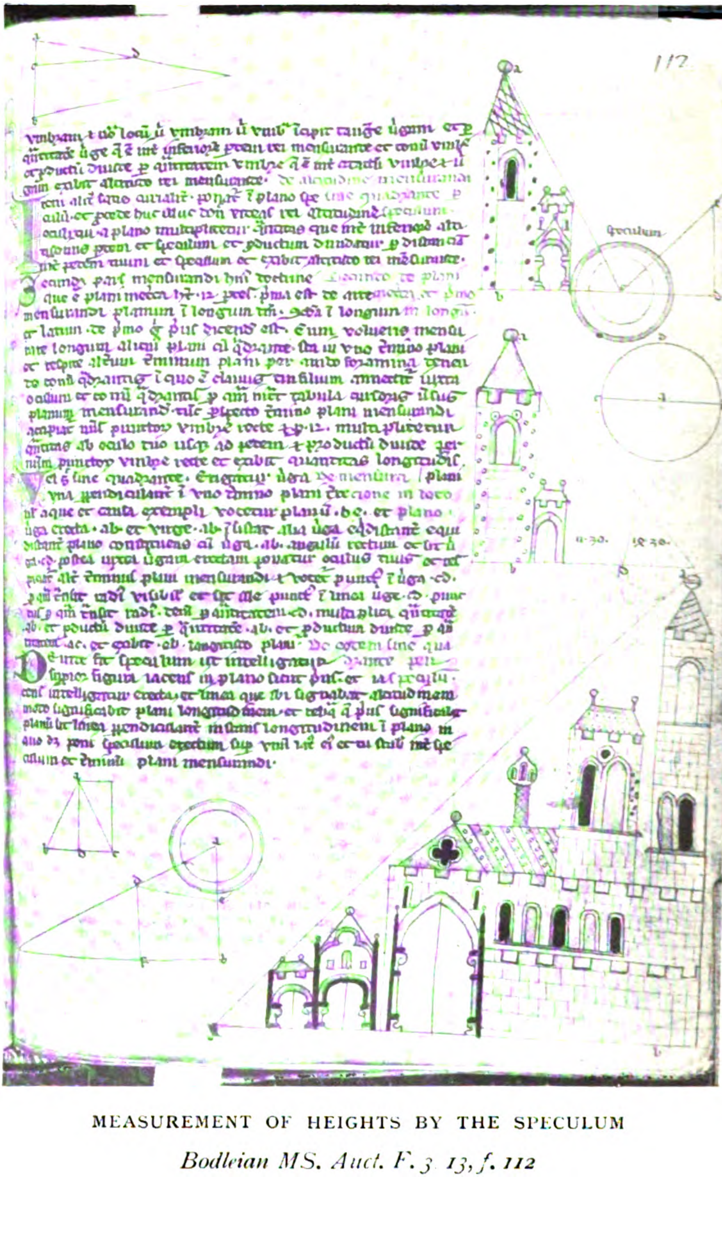
The following quotation alludes to the use of this instrument by an Oxford traveller of the fourteenth century.

'That which you see described in this table of those foure Iles is taken from the journal of James Knox of Bolduc or the Busse (= Jacobus Cnoyen of Bois-le-Duc), who reporteth that a certaine English Friar, minorite of Oxford, a Mathematician, hath seene and composed the lands lying about the Pole, and measured them with an astrolabe, and described them by a Geometrical instrument.[1]

John Dee adds the date 1360. The astrolabe is described as an astronomical instrument in vol. ii.

For the ready computing of the heights and distances of near objects, the back of the astrolabe was engraved with **Scales of the Shadows,** known as scales of *Umbra Recta* and *Umbra Versa*, each divided into twelve parts. The use of these scales is clearly shown in early manuscripts and books on surveying. For example, the height of a tower would be found by sighting the rule at the parapet, and reading the umbra recta divisions. Suppose this to be 8; then the distance of the observer from the tower multiplied by 12 and divided by 8 was considered to be the height of the tower. The method is only an approximate method which has long been superseded by trigonometry, but so long as the angles are small the error will not be great. Roughly the numbers correspond to the cotangents for the Umbra Recta, of the angles indicated by the alidade, multiplied by 12, and to the natural tangents for the Umbra Versa. The use of the Scales of the Shadows has been described by Chaucer. They were doubtless the prototype of the **Surveyor's Square** or **Quadrate,** an instrument which

[1] Mercator's *Atlas*, translated by Hexham, i, p. 44; Hakluyt i. 134.

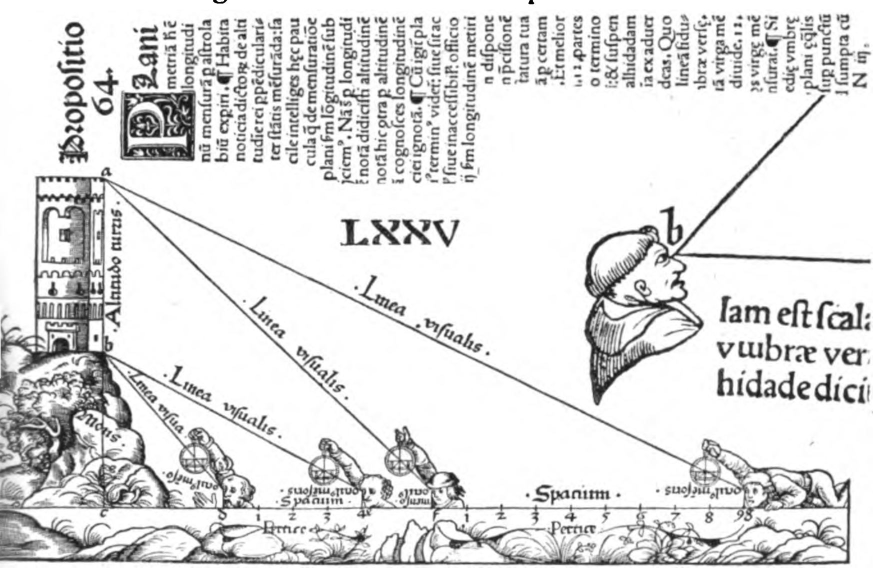


MEASUREMENT OF HEIGHTS BY THE SPECULUM

Bodleian MS. Auct. F. 3. 13, f. 112

is represented by a particularly fine example by SCHISSLER, in the Bodleian Collection. See p. 340.

During the Middle Ages the genius of a few men of science placed more instruments at the command of the surveyor. Chief of these was the **Quadrant,** an instrument which had great advantages over the Astrolabe in being less cumbrous and expensive and much



STÖFFLER'S SURVEYORS AT WORK WITH THE SCALES OF THE SHADOWS ON ASTROLABES, 1512.
Inset is the head of one of his observers shown on folio lxviii.
From Stöffler, Elucidatio Fabricae ususque Astrolabii.

more accurate, and soon supplanted it for survey purposes.

It is characteristic of the early literature on surveying, whether manuscript or printed books, that the operations described are illustrated with drawings of great clearness and considerable charm, which may even appear as part of the decoration on early instruments. In the accompanying figure is represented a method of measuring the height of a building by a mirror. We

attribute considerable importance to these graphic illustrations, because they were carried on into all the early printed books on Surveying, and served as a very real incentive to a study which might have otherwise appeared hopelessly difficult to the uninitiated. The first treatise in English on Surveying dates from the fourteenth century. It is a translation of the second part of ROBERTUS ANGLICUS on the Quadrant, and is entitled *Ars metrica*.

'Now sues here a Tretis of Geometrie wherby you may knowe the heghte, depnes and the brede of most what erthely thynges.' (Halliwell, *Rara Mathematica.*)

And a further extract is given in explanation of the Quadrate, p. 337.

The application of trigonometry is usually ascribed to a Jew, Levi ben Gerson of Avignon (1321), but the high honour of having been among the first men of western race to teach the practical utility of the trigonometrical method belongs to the members of our early Merton School, whose treatises have been already noted on page 96. The works of RICHARD OF WALLINGFORD *De sinibus* and others are of interest, because they show that he must have been acquainted with Albategnius in the translation of Plato of Tivoli, where the word *sine* is first used. JOHANNES MAUDITH was teaching in Oxford in 1340. His early contribution to Trigonometry was *De chorda et umbris*. *Umbrae* (= tangents of present-day trigonometry) were functions of angles peculiar to the Arabian mathematicians. BRADWARDINE used the words *umbra recta* and *umbra versa* repeatedly in the sense of cotangents and tangents, thus anticipating Regiomontanus by a century. And last though not least SIMON BREDON, physician as well as astronomer, *c.* 1380, calculated a table of sines and used the words *arcus, sinus rectus, sinus versus*.

Therefore the members of the Merton School may be given the honour of having been the first European authors on Trigonometry.

The year 1648 contributed Pascal's discovery that **Torricelli's barometer,** invented five years earlier, could be used for the measurement of heights above the sea-level.

In 1669 Jean Picard greatly improved the Quadrant by the application of a telescope provided with cross wires.

Surveyor's Quadrants and Quadrates

The Astronomer's Quadrant was no doubt derived from the somewhat simpler surveyor's quadrant by the addition of horary lines.

A practical surveyor is more concerned with the lengths of straight lines than with the value of angles. His quadrant was marked with two scales at right angles, drawn perpendicular to the sides of the quadrant and divided into equal parts. These limit the Quadrate. When referred to such scales the plumb line of the instrument will give not the angle of inclination of the line of sight to the horizon, but the trigonometric tangent of this angle, if it be less than 45°, or the cotangent if it be between 45° and 90°.

In ordinary quadrates the radius or side of the square is divided into twelve parts and the tangents or cotangents measured in parts are called *umbra versa* and *umbra recta*—terms which recall the Arabian origin of the arrangement.

The fundamental problems of surveying could be worked out readily by a simple square either solid or hollow, as is described in the *Treatise on Practical Geometry*, translated into English in the fourteenth century.[1]

Use of the *Quadrate*.

'This Tretis es departed in thre, þat es to say, hegh mesure, playne mesure and depe mesure. . . .

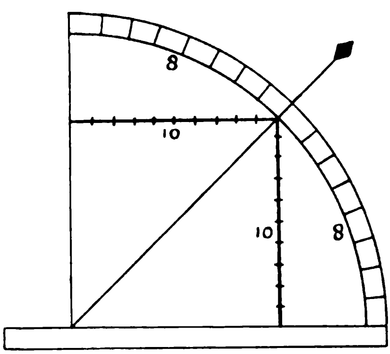
'The quadrat þat es to say 4 square whilk es descryvede that es to say schewed in the quadrant has tuo sides. That es to say the side of the umbre toward and the side of the umbre froward; and aither of these 2 sides es departed in 12 even parties. When you holdes the cone of the quadrant, that es to say the cornel of the quadrant even upryght, in whilk cornel es the nayle whereby the perpendicle henges, than the circumferens, that es to say the cumpasse es toward

[1] In a Tretis of Geometri (fourteenth century), Bib. Sloan. Mus. Brit. 213 xiv, f. 120. Published by Halliwell, *Rara mathematica*, pp. 58-9.

the erth. Than that side of the quadrat whilk es nere ye es called the vmbre toward and that other side es called the vmbre froward, and the 12 departynges of aither of tho sides are called poyntes. Than es a poynte the twelft parte of any thyng, namely of outher side of the quadrat in the quadrant.' [A detailed description follows.]

A similar description of the method of measuring heights is contained in the *De altimetria*, in the Bodleian,[1] which may have supplied the geometric part of the *Treatise of the Quadrant* attributed to Ro: Anglicus, *alias* John of Montpellier, of which an important and very early version dated 1276 is preserved at Cambridge (No. 1767).

In the time of Leonardo of Pisa, 1220,[2] practical surveyors used a quadrant with the limb divided into sixteen parts, inside which a square was inscribed with sides divided into ten equal parts.



When by the use of this instrument an observation is made of a distant high point, a plumb line let fall from the middle point cuts the graduated limb and one of the divided sides of the square; from the first the angle is read, from the second the tangent or cotangent.

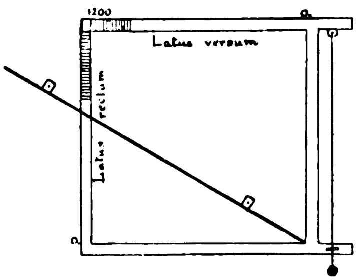
A perpendicular from any given point to a given line on the field was found as follows:—The Surveyor having placed himself on the spot from which the perpendicular shall start, fixes a cord or tape to it and proceeds with the other end of the cord to the line to about where the perpendicular should cut. Then the cord is stretched, so as to be lifted off the ground and is moved right and left along the line. Then the two points where the end of the cord cuts the line are marked; and half-way

[1] MS. Digby 174, f. 145.
[2] *Practica Geometriae*, 1220.

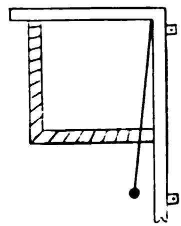
between the two marks is where the desired perpendicular must fall.

Early treatises on surveying are frequently illustrated with excellent pictures showing the method of using quadrants and quadrates. A good example, Bodleian S. C. 2177, of about the year 1275 shows clearly how the height of buildings may be measured.

During the fifteenth century there arose a craving for instruments of greater precision. Purbach (1423–62) contrived a 'Quadratum geometicum', which he dedicated to John, Archbishop of Gran in Hungary. Its sides, called *latus versum* and *latus rectum*, were 2 ells long



PURBACH'S QUADRATUM GEOMETRICUM, 1450



TARTALEA'S QUADRATE, 1537

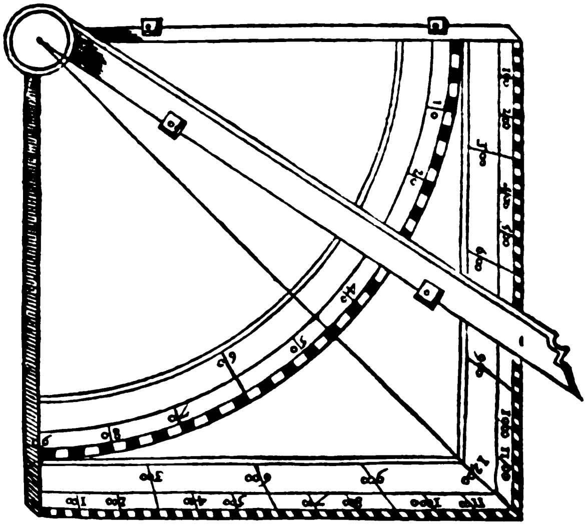
and were divided into 1200 parts, so that each division was about 1 millimetre long. The instrument was furnished with a plumb bob, and an alidade with sights. Purbach made practical use of his table of sines for geodetic purposes.

The advantages gained by elongating the leg of the Quadrate carrying the sight vanes were set forth by Nicolo Tartalea in his *Nova Scientia Inventione*, 1537. In Paris, Jean de Merliers also wrote on *L'Vsage du Quarre Geometrique* in 1573, but he had possibly been anticipated by a Norfolk man Dr. William Cuningham (1531–86), who wrote a treatise, now lost, entitled *A new Quadrat, by no man ever publish'd.*

Digges' Geometrical Square. **1571.**

Described and figured by Digges in his *Geometrical Treatize named Pantometria*, 1571. It reproduces the

division of the sides into 1200 parts, as recommended by Purbach.



GEOMETRICAL SQUARE, 1571.
Designed by Leonard Digges of University College.

256. Geometer's Quadrate. 1579.

Perhaps the mathematical instrument for which, with a picture of Dr. Junius, £100 was paid to Dr. Vossius in 1679 (V. C.'s accounts). Cf. p. 384. It is certainly 'curioso opere elaboratus'.

Inscribed on back

Christophorus Schissler
Geometricvs ac Astronomicvs Artifex
Augustae Vindelicorum faciebat anno domini 1579

In gilt brass frame $13\frac{5}{8}$ inches square. It is packed in an oak box, which is also fitted to hold a clinometer.

A superb example of this master's art. It was formerly regarded as one of the sights of the Library and was kept in a cupboard in the wooden stand of the Armillary Sphere. Uffenbach saw it on Aug. 19, 1710, and was told by Crab, the sub-librarian, that it was made of pure gold.

'There are many Scalae and calculations on it, but rather badly graduated, although the good Crab (the Assistant Librarian) to enhance its value, said that the work was even more precious than the material of which it was made. Gold would have been worth more to me in every way. With but a small quantity of this badly applied gold, one could purchase a decent gilt brass instrument which would be more accurate and neater, as well as more convenient to use, than this one. This golden Quadrant is more than a Rhenish Foot square, and probably weighs 6 to 8 pounds.'[1]

This instrument has hitherto been described as a Quadrant, no doubt on account of the Quadrantal Scale on the face, but as far as its instrumental part (on the back) is concerned, it is more correctly described as a *Gnomo geometricum* or Geometer's Quadrate of George Purbach[2] or as a Geometrical Square,[3] since it is not an instrument for measuring angles directly, although angles can be found out by the use of tables, so much as for measuring heights and distances by the use of modified scales of Umbra recta and Umbra versa, which Purbach thirty-five years previously had called 'Latus rectum' and 'versum'. Schissler's Quadrate was constructed on the same principle. On the face is engraved a scale in the form of a quadrant $9\frac{3}{8}$th in. radius, to the angle of which is attached a movable *cursor* or rule. The scale is surrounded by a frame of reliefs illustrating the use of surveying instruments. The reliefs are of brass, gilt, and are screwed on to the base plate.

The quadrant-shaped area is closely ruled with 200 parallel lines about $\frac{1}{23}$ inch or 1·1 mm. apart, and numbered 0 to 200 in fives both along the upper margin and along an arc by which all the lines are bisected.

The upper side, from which the parallel lines start, is also more minutely graduated along oblique lines into 1,000 *Puncta distant' locorum*, and a similar elaborate scale marked *Scala geometrici cursoris* is engraved on the rule which swings round the graduated limb of the quadrantal scale, and traverses with its fiducial edge the parallel lines, which is again divided into 1,000 *Puncta altitudinis stationis* corresponding in level with the numbers of the *Puncta distant' locorum*.

[1] Z. von Uffenbach, *Reisen*, iii, p. 100.

[2] G. Burbachius (Purbach), *Gnomo geometricum*, Nuremberg, 1544, fig. on p. 62r.

[3] L. Digges, *Pantometria*, 1571, chap. 22.

By these means the scales can be easily read to about a fifth of a millimetre.

The scale has features in common with the *Instrumentum sinuum* or *Quadrans primi mobilis* of Peter Apian, 'jam recens inventus' in 1541, which was subsequently developed into the *Trigonall Sector* of John Chatfielde, 1650, and the *Sinecal Quadrant* of navigators. Schissler appears to have adapted the 'Instrumentum sinuum' for the special use of surveyors of land.

In respect of the increase in the number of graduations and of the use of transversal rows of dots, the instrument belongs to the period of Tycho Brahe, when much money was spent on great striving after minuteness of graduation. See figure on p. 168.

The quadrate is framed in a series of reliefs of geometers engaged in surveying, somewhat in the nature of text-book illustrations, showing a beginner the right method of taking observations. The pictures belong to a period when human figures were considered helpful to elucidate the method of using scientific instruments. Text-books on optics, for example, may be grouped in periods by the character of their illustrations; in the oldest the observer is represented by a full-length figure with his eyes and instrument not necessarily in the line of sight,[1] subsequently by a head,[2] later still by eyes alone[3] which become more and more diagramatized and are finally omitted altogether, so that in modern books there is nothing that is of human interest at all save perhaps the letter E. Schissler gave his figures of observers a further touch of realism by dressing several in turbans, a touch that reminds us of the oriental origin of geometric lore. The time was not far distant when the only good geometers and astronomers in Germany were Arabs, or those who had been taught by them. A similar turbaned figure was also introduced by Schissler into his Dial of Achaz. Further realism is given to the picture by the birds, which, disturbed by the surveyors, are flying about in all directions, and by the squares and compasses that are untidily left about the fields.

[1] As in the works of Stöffler or Apian *c.* 1541 and others. See figs. on pp. 333, 335, and 353. [2] See figure on p. 335.
[3] e.g. Leybourn, *Curs. Math.*, p. 554 and Gunter's figures on p. 355.

The marginal reliefs illustrate methods of obtaining the results listed below by the use of the Geometer's Quadrate, the ordinary Quadrant, the Square, and the Jacob's Staff.

Left side.

1. Height of an inaccessible tower on the further side of a torrent, from two stations by the Geometer's Quadrate.
2. Distance along the ground by the Square.
3. Height of a spire by use of the ordinary Quadrant at two stations.

Lower side.

4. Depth of a ravine below a hill top by the Quadrate.
5. Angular elevation of a tower on a hill by the ordinary Quadrant.
6. Distance of a point on the ground by a large Quadrate.

Right side.

7. Width of top of distant tower by the Baculus astronomicus or Jacob's staff.
8. Height of the parapet above the upper storeys of a distant tower by the Quadrate.
9. Height of a tower by a Quadrant.
10. Distance of a house on a hill by the Quadrate.

Upper side.

11. Geometer crawling on the ground to observe the elevation of a tower probably with a mirror. Cf. Apian, Proposition 14.
12. Geometer on a tower estimating the height of another building with the Quadrate. Cf. Apian, Proposition 11.
13. Distance of a tower on a hill from two stations by two observers with one Quadrate.
14. Angular elevation of a town on a hill by ordinary Quadrant.

Within the corner of the frame not filled by the scale of sines is a pictorial relief in which two surveyors and their assistants are engaged in the triangulation necessary to measure their distance from a village on the farther side of a river containing two ships, a whale, and a mermaid. In his decorative work Schissler appears to have been very fond of introducing water, which he usually tinted blue.

On the back are those parts which entitle this instrument to be regarded as an instrument of observation, as well as tables of numbers for calculation of results, and the inscriptions of the maker.

Observations were made by sight vanes (now missing) that were fixed in two holes on the *Regula perspiciendi*, a rule 1 ft. 6 in. long, and divided into 285 parts.

At the side (? below) is a slider carrying the *brachiolus* or arm of attachment for the plumb line of the quadrate, probably for use in connexion with the *Vmbrae versae et rectae*.

The back is covered with a table of numbers, the *Tabula scalae geometricae mille pvnctorum*, in ten columns each containing three rows of figures headed

PVN ZAL BRV

(= Puncta, Zalen, Brüche or Points, Numbers, Fractions). The Puncta run from 1 to 1,000.

Scala deferentis qui regulam hypothenusa adducit atqz abducit.

Tabula scalae geometricae ducentorum punctorum utriusque umbrae.

The small remaining space is filled with two small engravings, one of a geometer seated at a table and working with instruments, and the other of a diallist examining a sundial.

This instrument belongs to a period when the great utility of detailed mathematical tables was beginning to be recognized. Peter Apian had published in 1533 a table of sines with the radius divided decimally. Sixty years earlier Regiomontanus had calculated tables of sines of angles for the radius 60,000,000 and an edition of his tables was printed in 1531. Schissler designed his instrument to serve both for observation and for ready reckoning: as he explains in the inscription

In hoc quadrante summa omnium tractorum numerorum qui in mille partibus contingere possunt sine omni calculatione invenitur.

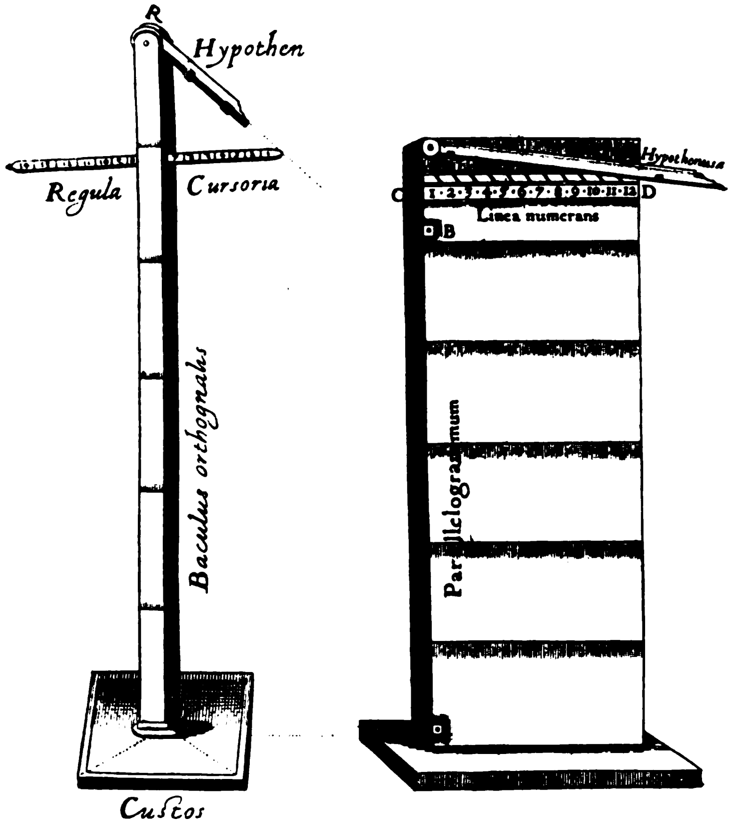
The Triquetrum

The Triquetrum or **Ptolemy's Rods** is also described as an astronomical instrument. It was the prototype of many topographical instruments in which three rules are

employed for obtaining heights and distances. As ordinarily used, one rule was held vertical, a second was directed towards the object whose zenith distance was to be measured, whilst the third gave the distance between fixed points on the other two. The zenith distance was then taken from a table or computed from the lengths of the rods. (Reeves.)

An important adaptation of the principle of the Triquetrum is shown in the 'Baculus geometricus' invented by ROBERT FLUDD of Christ Church.

Fludd's Baculus geometricus. 1624.



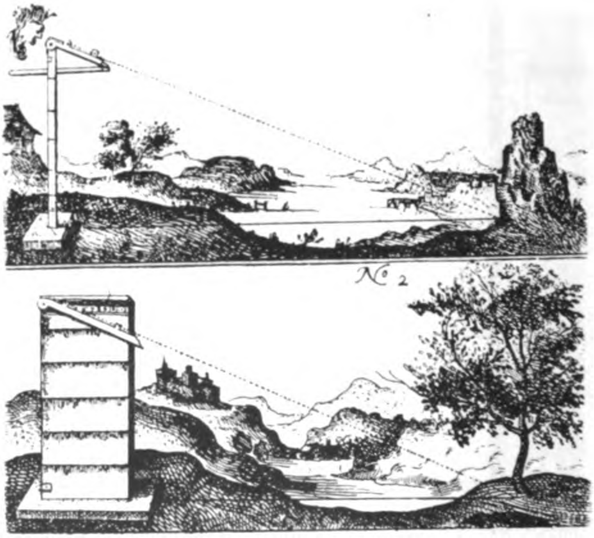
FLUDD'S BACULUS GEOMETRICUS AND PARALLELOGRAMMUM, 1624.

Described by the inventor in his *Macrocosmi Historia*, pp. 271–291. The staff or *baculus orthogonalis*, 6 ft. in height, is divided into six equal divisions and is provided with a plumb-line. At the top is hinged a *regula hypothenusa*, 1 ft. 6 in. long, with pinhole sight-vanes. One foot below the 'hypothen', a *regula cursoria*, ending in a copper knob, and divided into 14 equal parts, is threaded through the *baculus orthogonalis*, so as always to be at right angles to it.

Observations may be made with the instrument lying flat on the ground, or supported in various ways, or standing upright in a *custos* or square wooden stand.

All three rods were sometimes fitted with sight-vanes.

The same instrument, though in a very different form, was the Parallelogrammum of Fludd.



FLUDD'S BACULUS AND PARALLELOGRAMMUM IN USE, 1624.
De Macrocosmi Historia.

Fludd's Parallelogrammum. **1624.**

loc. cit., pp. 276–289.

Here the staff and *cursor* are replaced by a rectangular board, measuring 6 ft. × 2 ft., fitted with sights in the upper corner of which is pivoted the *regula hypothenusa*

or sight rule, which traverses a scale of 12 divisions representing the *cursor* of the last-described instrument.

The Joint Rule and its Modifications

The method of the direct measurement of angles by two sticks, which are either fixed or hinged together as in the carpenter's bevel, has led to the elaboration of a series of instruments, such as the **Joint Rule** or **Carpenter's Rule,** made and described by John Brown, philomath, in 1661, and to the triradiate form of which there is an early example in the Evans Collection.

Builder's Surveying Instrument. **1579.**

For laying out walls at right angles. L. Evans Collection.

'*A. Descrolieres facie* 1579.'

With sights. Arms marked

Pro declinatione muri, *Pro Initys signorum.*

Joint Rule or '**Squadra Zoppa**'. **1617.**

L. Evans Collection.

'Christof Tressler der Elter Mechanicus Anno 1617'.

Brass gilt. Arms marked AE and AF, provided with sliding cursors G and H by which measures can be made to $\frac{1}{100}$ inch.

Blagrave's Familiar Staffe. **c. 1586.**

An instrument for estimating heights and distances by the principle of similar triangles. It is of peculiar local interest on account of the circumstances which led John Blagrave of Swallowfield, by Reading, Gentleman and 'well willer to the Mathematickes', to publish *A Booke of the making and use of a Staffe, newly inuented by the Author, called the Familiar Staffe*, London, 1590, with a woodcut of the instrument on the title-page. It may almost be regarded as an Oxfordshire invention, for in the summer of 1589 Blagrave happened to be present on a festive occasion at Greys Court in Oxfordshire when Sir Francis Knollys was expecting the return of his grandson Robert Devereux, Earl of Essex, from the 'then late desperate voiage performed into Portingale'. To pass the time Sir Francis and his sons amused themselves by shooting with a cannon at a mark,

and the eldest son, Sir William, by being 'verie desirous and inquisitive' of Blagrave as to how the distance of the mark whereto they shot could be obtained, eventually determined him to publish an account of the construction of the Familiar Staff and of its use in surveying and gunnery.

Blagrave's Familiar Staff, 1598.

The instrument was like a pair of compasses with legs five feet long and with a sliding sight pin on each leg. One of the legs was graduated according to a method that was commended to the 'ingenious mathematicall minded gentleman, Master Auditor Hill'.

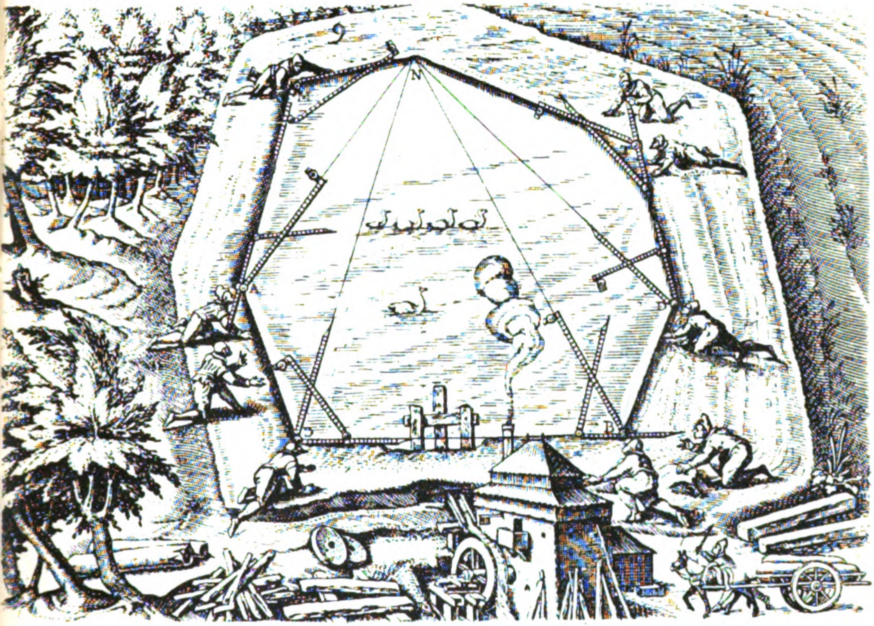
They were made by John Reade of Hosier Lane, 'a verie arteficiall workeman'.

The book sets forth how that the use of the Familiar Staff is 'so generall that it readily performeth all the severall uses of the *Crosse staffe*, the *Quadrate*, the *Circle*, the *Quadrante*, the *Gunners Quadrante*, the *Trigon*, every one in his owne kinde, and with no lesse methode and facillitie, both for Sea and Land'. Its superiority over the Cross-staff, or *Baculus geometricus* of Gemma Frisius, and especially when the latter is hung 'as it were by the haire of the head, with his armes abroad, for then is his so well boasted facillitye quite gone', is fully explained in chapter 2.

The Trigonometre.

With the Trigonometre distances could be readily found by the adjustment of three movable arms with engraved scales. The observer would stand at one end of a measured base line and sight one of the arms along it, aiming another arm at the object of which the distance is required: then, moving the instrument to the other end of the base, the third arm is aimed at the same distant object. The intersection of the two arms gives the position of the object, and its distance can be read off by the scales.

The working of a similar Geometric Triangular Instrument by M. Jobst Burgi was illustrated with many charming engravings by Benjamin Bramer in 1684.[1]



JOBST BURGI'S SURVEYORS AT WORK BY A MANY-SIDED POND WITH THEIR 'GEOMETRIC TRIANGULAR INSTRUMENTS'. 1684.

SURVEYING SECTORS

There are two interesting Survey Sectors in the Evans' collection.

$8\frac{9}{16}$ inch Sector with slit and string sights. **18th cent.**
'*blondeau f.*'

$13\frac{1}{2}$ inch Sector. **Early 18th cent.**
By 'BVTTERFIELD A PARIS'.
With ornamental bracket for a compass.
Mounted on a ball-and-socket jointed head, for attachment to a staff.

[1] B. Bramer, *Bericht von M. J. Burgi Geometrischen Triangular Instrument.* 1684.

SURVEYING INSTRUMENTS OF THE SEVENTEENTH AND EIGHTEENTH CENTURIES

The Surveying Instruments of the seventeenth and eighteenth centuries included several which will be appropriately described under the head of Astronomical Instruments. A special type of one of these, the Quadrant (see vol. ii, p. 179), is connected with the name

GUNTER'S QUADRANT, 1624.
Foster, The Works of Edmund Gunter.

of a member of Christ Church, EDMUND GUNTER, who effected notable improvements in this instrument in the seventeenth century, and whose name has already been mentioned in connexion with the surveyor's chain.

Among the other instruments used by Geographers and Astronomers alike were the

- Cross-staff.
- Back-staff.
- Cross-bow.
- Octant.
- Sextant.

In 1685 an anonymous member of the Philosophical Society of Oxford, JOHN CASWELL, Vice-Principal of Hart Hall, communicated a paper to the Royal Society on *The Solution of three Chorographical Problems*,[1] in which he considered 'three problems which may occur at Sea in finding the distance and position of *Rocks*, *Sands*, etc., from the shore; or in surveying the Sea Coast; when only two objects whose distance from each other is known, can be seen at one station'. The instruments mentioned are the surveying Semicircle, the Cross-staff, and the Telescopic Quadrant.

THE CROSS-STAFF, BACK-STAFF, AND CROSS-BOW

Cross-staff.

Synonyms:

Baculus Jacob. Levi ben Gerson, †1344.
MS. Cod. lat. Mon. 8089, in Munich.

Virga visoria. George Purbach, *b.* 1423, *d.* 1462.

Radius astronomicus. Regiomontanus, *c.* 1470.
Regiomontanus was the pupil of Purbach and has been shown to have been acquainted with Levi's description of the Cross-staff by J. Petz, *Mitt. des Ver. Geschichte Nürnbergs*, vii, p. 123.

Baculus or radius astronomicus. Pedro Nunez, *De arte atque ratione navigandi*, Coimbra, 1546, lib. i, c. 6, originally printed as an appendix to *Tratado da esphera*, Lisbon, 1537. Cf. also *De regulis et instrumentis* in *Opera mathematica*, Basel, 1566, p. 73.

Balestilha. Portuguese and Spanish seamen.
Derived from the Arabic 'âl balista' (Bittner).

Arbalète. French seamen.

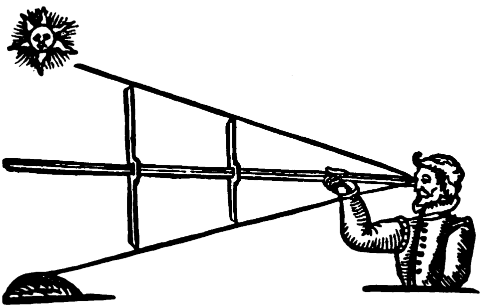
Cross-staff. English seamen.

The invention of the Cross-staff was made by Levi ben Gerson, a learned Jew of Bañolas in Catalonia, who dedicated a description of it to Pope Clement VI in

[1] *Philosophical Transactions*, No. 177, p. 1231. Caswell had had some experience in surveying in 1682, when he was employed by Adams in the Survey of Wales. He had used a quadrant with telescope sights made according to Flamsteed's directions. He measured the heights of several of the Welsh hills. The Wrekin, 466 yards; Clee Hill, 600; Penmaenmawr, 515; Cader Idris, 970; Snowdon, 1,240 yards. (*Letter* from Flamsteed to Wren, in Wren, *Parentalia*, p. 253.)

A.D. 1342, but he may not have been the originator of the instrument. It does not appear to have been commonly used by seamen much before the first decades of the sixteenth century, for whereas P. Nunez mentions it in his essay published in 1537, there is no mention of it by Columbus, Vasco da Gama, Cabral, and Duarte Pacheco Pereira, all of whom navigated with the astrolabe and quadrant. A. Vespucci in 1508 was instructed to examine pilots in the use of the same two instruments.[1] HARIOT (*c.* 1600) was the first Oxford man to write on the Cross-staff. (MSS. Addit. 6788.)

The Cross-staff was a simple instrument for observing the altitudes of heavenly bodies and stellar distances. It was a contrivance of particular utility to mariners because by it the sun and the horizon could be seen at the same time. It was composed of a cross bar or 'transom' (sometimes two cross bars) which could be slid along a graduated staff of wood. To make an observation, the end of the staff was placed against the eye, and the cross bar was shifted until the two ends of the cross bar, serving as sights, were brought into line with two objects. Then the angle between two objects could be measured by the position of the cross bar on the graduated staft.

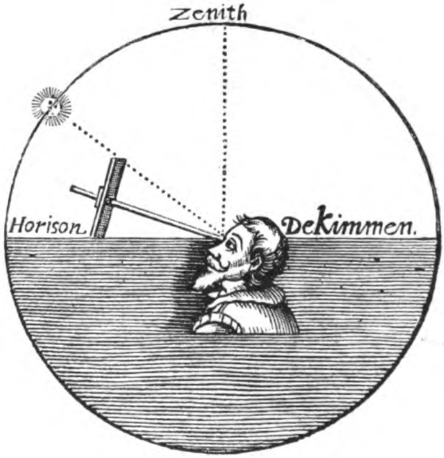


CROSS-STAFF, 1594.
John Davis, Seamen's Secrets.

Two early engravings show the method of using the instrument. JOHN DAVIS' Cross-staff of 1594 had two slides, PETER GOOS' (1658) had only one.

[1] *Navarrete Coleccion*, iii, Dec. 7–9, quoted from Ravenstein's *Behaim*.

The observers are taking the altitude of the sun above the horizon, with the staff held with the movable arm vertical and just covering the sun and touching the horizon. There was no real need for the additional refinement obtained by the partial immersion of the observer in the sea as indicated by the representation of Goos.



THE CROSS-STAFF, 1658.
Peter Goos, Sea-mirror.

An obvious inconvenience was the penalty of temporary blindness by the observer getting the sun in his eye. But the wise man used the instrument when the sun was partially obscured by cloud.

Some kind of shade was no doubt employed, but this inconvenience led to the Cross-staff's being superseded by the *Back-staff*.

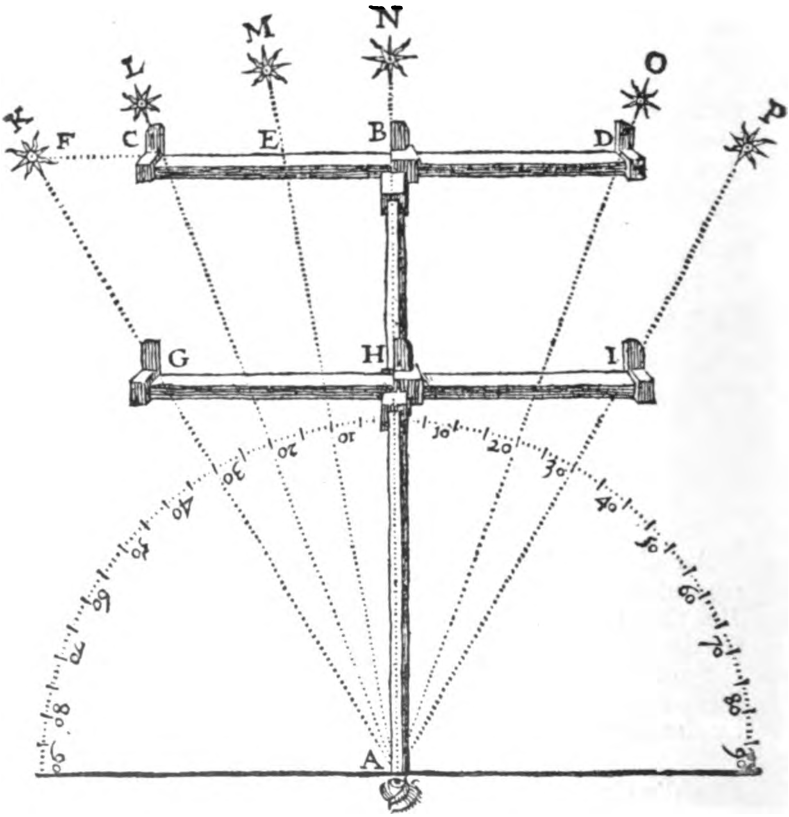
Fludd's Cross-Staff. **1617.**

In the instrument described by ROBERT FLUDD of Christ Church, the graduated staff, or *baculus*, was three feet long and was divided into six equal parts. The sliding transom, or *cursor*, was one ft. long with the ends hollowed out for a distance of three inches at each end, so that the middle piece of 6 in. could also be used

in lieu of the whole width of the cursor, when the subtended angle is small. *Macrocosmos*, pp. 275–285.

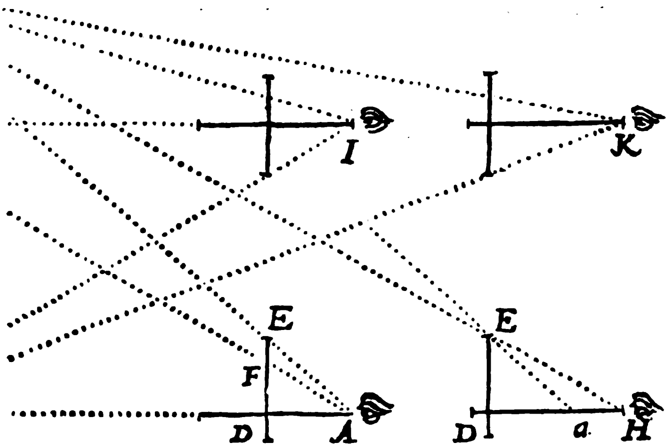
Gunter's Cross-Staff. **1624.**

Seven years later, another member of Christ Church, EDMUND GUNTER, published a work on *The Crosse-staffe* in which the method of using the instrument is fully



THE CROSS-STAFF OF GUNTER OF CHRIST CHURCH, 1624.

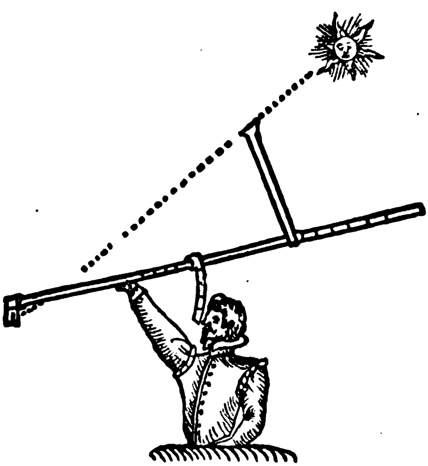
explained with the aid of the clearest diagrams that had been published up to that time. It will be noted that the observer who figures so prominently in early surveying pictures has been reduced to a single eye.



DIAGRAMS OF THE USE OF THE CROSS-STAFF, 1624.

Back-staff.

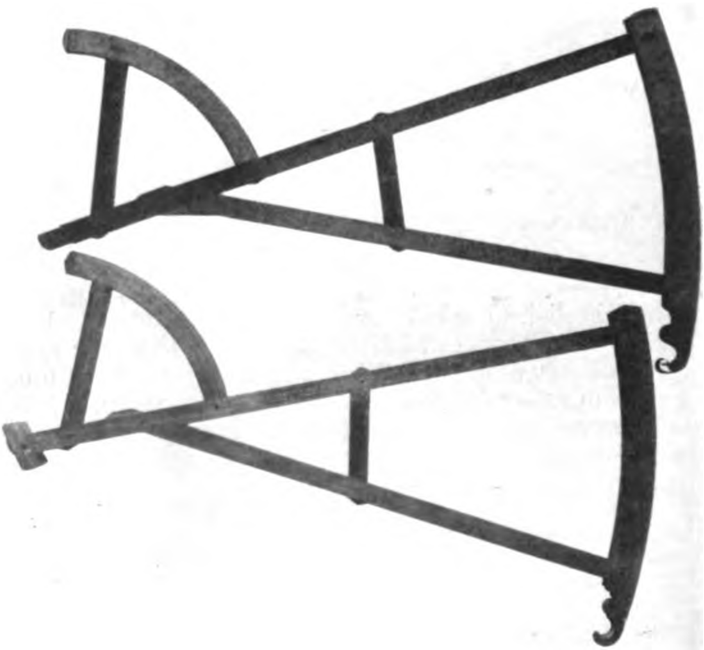
The English Quadrant or Back-staff was invented by Captain JOHN DAVIS, of Limehouse, about the year 1540 for the observation of the sun's altitude at sea without the painful necessity of looking direct at the sun. It is often known as Davis' Back-staff. It came into very



DAVIS' BACK-STAFF, 1594.

general use, and superseded the old Jacob's staff, described with illustrations in many early works, e.g. Metius, *Primum mobile*, which had been in use among the Portuguese navigators.

According to the *New English Dictionary* the first recorded use of the term Back-staff is to be found in 1627 in Capt. Smith's *Seaman's Grammar*, xv. 73: 'A Crosse



Nos. 257, 258. Davis' Back-staff.
Pitt-Rivers Museum.

staffe, a Backestaffe, an Astrolobe'. But the instrument in its earliest form, with the method of using it, is shown in a woodcut in John Davis' *Seamen's Secrets* in 1594.

It consisted of a combination of an arc and a chord mounted on a staff. Both arc and end of staff have sights; the chord ended in a shadow vane which cast

a shadow on the staff sight. It was the observer's task to adjust the arc sight until he saw the horizon line and chord shadow coincide.

257. English or Davis' Quadrant or Back-staff.

Pitt-Rivers.

Name plate missing.

For use cf. Stone's *Bion Math. Instr.*, p. 204.

258. English or Davis' Quadrant or Back-staff.

Pitt-Rivers.

Edm : Culpepper fecit.

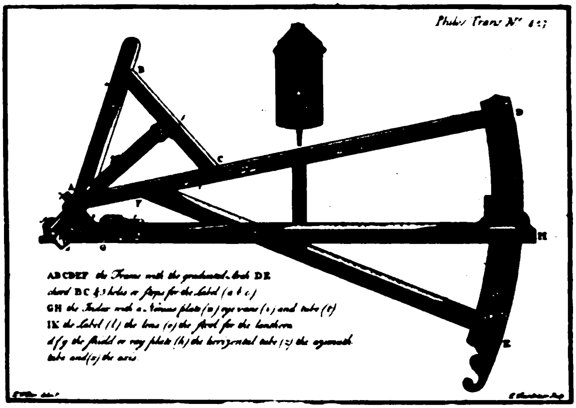
Pear-tree wood. Decorated with rose and fleur-de-lys stamps.

The instrument was commonly made of pear wood or some hard wood, and consists of a radial bar on which is marked the central line, and to which is fixed on one side a limb of 30° and about 2 ft. radius, and in the same plane on the other side an arc, to the same centre, of 60° and about 6 in. radius. The arc and limb are both divided into degrees so that the 60° on the former and the 30° on the latter both correspond to the central line of the bar. The degrees on the limb are subdivided by diagonal lines and concentric arcs so that readings can be made to 1′. On the other side of the limb are engraved tables of the sun's declination and right ascension. A sight works on the limb, and a 'shadow' vane on the arc; to the centre is fixed the 'horizon' vane.

To observe the sun's altitude the observer must stand with his back to the sun, and holding the back-staff upright, the limb towards him and the arc uppermost, must move the sight on the limb until he can see the horizon through the slit on the horizon-vane at the same time that the edge of the shadow of the 'shadow' vane falls on the same slit. The sum of the readings of the arc and the limb will then be the sun's apparent zenith distance.

For further details cf. Stone's *Bion Math. Instr.*, p. 204, pl. xx.

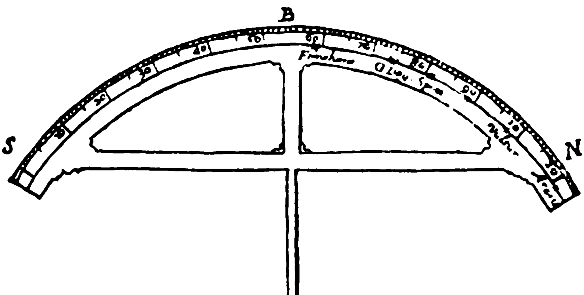
Back-staffs bearing the maker's name *S. Wright* were made *c.* 1720.



Elton's Artificial Horizon fitted to Back-staff.
Philosophical Transactions, 1732.

The Cross-bow.

The Cross-bow was a rather cumbrous improvement on the Back-staff. By its use the altitude of the sun could be determined with one reading of the position of a movable eyesight on a graduated arc. The observer aligned the two sights with the horizon while the shadow of a vane at the upper end of the arc fell upon the sight in the centre of the arc.



Cross-bow, 1624.
After Edmund Gunter, Sector.

To find the latitude, the upper or shadow vane was set to the declination and then, as with the Back-staff, the observer with his back to the sun moved the lower

THE CROSS-BOW, 1624.
After Gunter, l. c.

sight along the arc until the horizon line was seen to coincide with the shadow of the upper vane.

We have, unfortunately, no example of this instrument in Oxford.

OCTANTS AND SEXTANTS

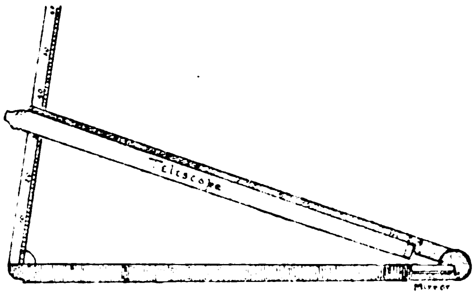
Sextants were certainly in use among the Arabians. As early as A.D. 992 Chogandi, for measuring the obliquity of the ecliptic, erected one of huge size in Bagdad, which which is said to have had a radius of 60 ft.[1]

Tycho constructed several sextants. One of $5\frac{1}{2}$ ft. radius was mounted so as to turn on a vertical axis with one end radius kept horizontal by reference to a plumb line hung from the middle of the radius.

The origin of the modern sextant is undoubtedly to be found in a suggestion made by HOOKE in 1666, namely, that by the use of a reflecting mirror in the quadrant, it would be possible for the observer to see two objects, between which the angular distance is to

[1] L. Sédillot, *Mémoire*, p. 204.

be measured, at the same time superimposed upon each other.



HOOKE'S REFLECTING INSTRUMENT, 1666.

At the meeting of the Royal Society on August 22, 1666, Hooke 'mentioned a new astronomical instrument for making observations of distances by reflexion, and was desired to give order for the construction of it, and to produce it before the society', and on Sept. 12 he 'presented his new perspective for taking angles by reflexion; which was approved of by the society'. It was a time of 'public disorder and unsettlement by reason of the late fire'.

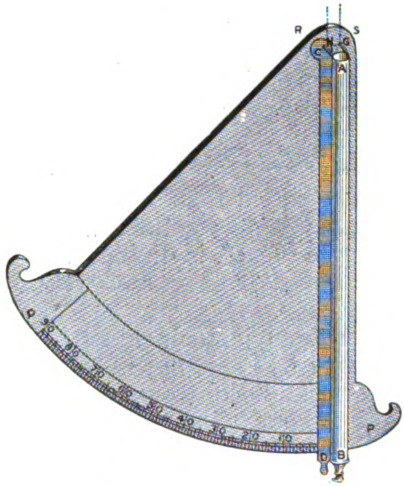
Sir Isaac Newton, realizing that an instrument designed on this principle would be of great use to mariners, in 1700 sent a description of one to Halley (Astronomer Royal 1720). There the matter rested until after Halley's death, when the description was found among his papers, and was published forty-two years after the date of the letter.[1]

In the meantime the invention had been made independently. A really serviceable instrument, showing considerable advance on Newton's idea, had been constructed by JOHN HADLEY in 1731.[2] Great accuracy in the readings was secured by the introduction of a telescope, and to all intents and purposes Hadley's octant (or quadrant) was very similar to the well-known and handy sextants in use at the present day.

[1] *Phil. Trans.*, 1742.

[2] The reflecting Sextant had also been invented independently by Godfrey of Philadelphia. Dreyer, 'On the invention of the Sextant', *Astronomische Nachrichten*, 115, No. 2739.

But although a telescope was included in Hadley's original description, in instruments for common use



NEWTON'S REFLECTING OCTANT, *c.* 1700.
Philosophical Transactions, 1742.

among seamen, pin-hole sight vanes were at first considered to be good enough, and they certainly cost less than the telescope.

The Octant.

The circular arc of the instrument being originally one-eighth of the circumference of a circle, it was called an 'octant', and as the double reflection makes each degree on the arc represent two degrees between the objects observed, the octant was therefore a measure of 90°, and thus obtained the name 'quadrant'.

In 1752 the octant was translated to the heavens by La Caille to figure as the constellation *Octans Hadleianus*, greatly to the honour of the inventor.

259. 18-inch Octant. 17—.

Oriel College.

With ivory scale and dark glasses and pin-hole sights.

260. 16-inch Octant. 17—.
Oriel College.

261. 10-inch Octant, ditto. 17—.
Pitt-Rivers collection.

262. 16-inch Octant, ditto. 17—.
Gunther collection.

With a pendent brass label marked E.

This octant, also called Hadley's Quadrant in honour of its inventor in 1730, has a limb which, though only subtending an angle of 45°, is divided and reads to 90°. The divisions are graduated on ivory, which is inlaid in a mahogany arc.

In Hadley's original instruments the scale was read to minutes by diagonal lines, but in the later octants of which these are examples (my own is of a type described as 'improved by Adams'), the 'vernier' was introduced. The vernier reading to minutes is also of ivory, and is fitted on to a brass index arm which carries a mirror whose plane coincides with the middle of the index and of the axis about which the index moves.

The two fixed mirrors, by means of adjusting screws, can be rendered exactly parallel to and perpendicular to the index mirror when the reading of the vernier is zero. There are three dark glasses. In the backsight are two pin-holes corresponding in height to the height of the edges of the quicksilver on the fixed mirrors.

The method of using the instrument is fully described in the Appendix to Stone's *Bion*, p. 269.

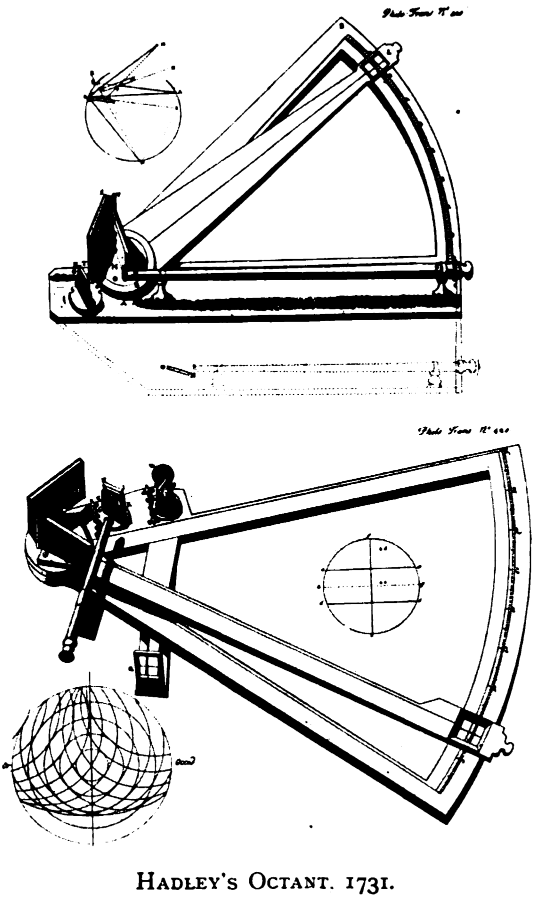
An instrument that was partly suggested by Hadley's Octant was the Distance measurer of Jonathan Cuthbertson, fully described by him in a pamphlet printed in 1792 in Rotterdam. He there states that he invented it in 1776.

'I should not neglect one perticular favourite use of this distane measure, which I hope it may be applyed to, which is I hope that a merchant ship when chased by a pirate, may know by this instrument before the pirate cums within gunshot, whether he is to resk his masts by seting more sail, or suffer him seff to be taken, which he must know by seeing throug the instrument whether the pirate gains upon him or not. . . .

'Great care must be taken of the instrument in such cases,

because if it should by an axident undergo any change, it would betray the users of it.'

Cuthbertson was probably the well-known author of a work on Electricity.



HADLEY'S OCTANT. 1731.
Philosophical Transactions, 1731.

The Sextant.

The circular arc of the octant was extended to $\frac{1}{6}$th of the circumference in order to be able to measure up to 120°, and Hadley's 'Quadrant' then became a Sextant.

The first person to propose this extension of the arc appears to have been Captain Campbell in 1757,[1] and a sextant on these lines was constructed by Adams. Sextants of the latest pattern are still made on the Campbell-Adams plan.

The sextant is not a very imposing instrument to look at, but it has perhaps taken a larger share in the work of mapping and charting the coasts of the world than any other instrument.

Hooke's Sextant. **21 June 1665.**

Exhibited at the meeting of the Royal Society on that date.

'It was made after the manner of a pair of dividing compasses, there being two three-feet tubes opening upon a joint in the manner of the legs of compasses, and a long strait screw moving in two motions, serving to take angles very exactly.' (Birch, *History of Royal Soc.* ii, p. 58.)

264. 6-inch Sextant with pin-hole sights. **1740–50.**

Oriel College.

By Jos. Jackson, London, No. 122.

265. 6-inch Sextant with telescope. **17—.**

Oriel College.

By J. Dollond and Son, London.

266. 6-inch Sextant with telescope **c. 18—.**
in mahogany case.

Daubeny Laboratory, Magdalen College.

18-inch Sextant. **17—.**

On loan to S. Kensington Museum.

By Bird.

The property of the Royal Astronomical Society.

[1] Grant, *Hist. of Phys. Astr.*, p. 487.

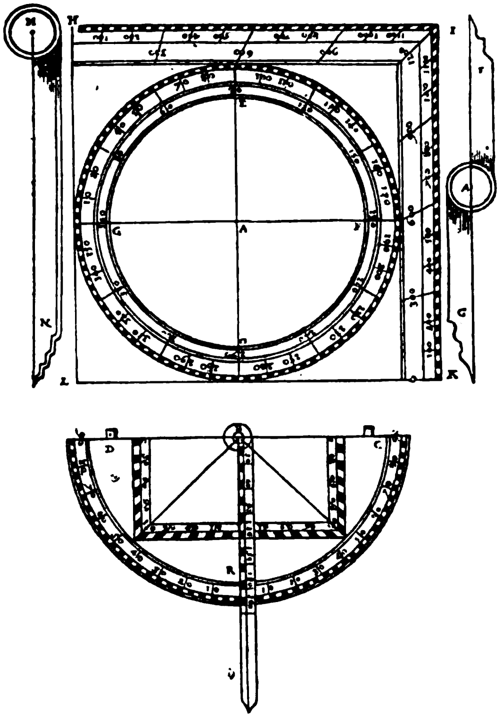
NO. 260
18-INCH OCTANT
Oriel College

NO. 261
10-INCH OCTANT
Pitt-Rivers Museum

NO. 265
DOLLOND'S 6-INCH SEXTANT
Oriel College

NO. 264
JACKSON'S 6-INCH SEXTANT
Oriel College

Mr. Reeves has suggested that the Diopter of the Alexandrine Greeks contained the first suggestion of the theodolite, and if only such an early type of instru-



DIGGES' THEODOLITE.
Pantometria, 1571.

ment had been fitted with circles, it would have comprised the essential principles of a simple theodolite.

The modern theodolite is the outcome of a large number of inventions by the gradual combination of which an instrument of great power has been made available for the purposes of the surveyor. The princi-

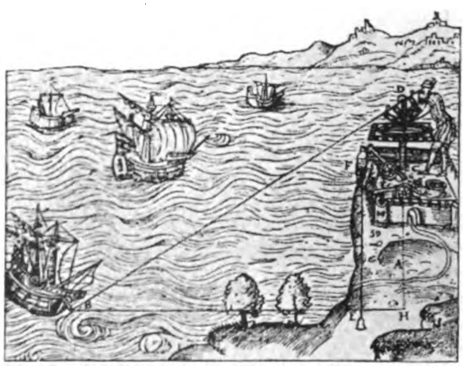
pal improvements have been made by Englishmen, and the originator was a member of University College.

The first undoubted theodolite[1] was constructed by Leonard Digges several years before it was described in detail by his son Thomas in 1571.

The **Theodelitus of Digges**[2] had a circle divided into 360°, or a semicircle divided into 180°, with an alidade, or index, bearing sights for measuring horizontal angles only. And this use is confirmed by Hopton (1611), Sturmy (1669), Moxon (1701), and Roy (1790).[3] So that the present application of the term to combined altitude and azimuth instruments is modern.

In 1607 J. Norden[4] states that 'Circumferentor' is a new name given to the very Theodelite, 'used in a sort otherwise then the Theodolite'. A compass box was fitted in the centre.

Digges's method of using his instrument is clearly shown in his book by an engraving which, moreover,



Range-finding with Theodolite.
Digges, Pantometria, 1571.

indicates that his invention was intended to meet the artillerist's need of rapidly and accurately estimating the

[1] The word theodolite is a favourite word with the composers of examination papers in which unusual derivations of words are asked. *Theodolite* = *theodelite*, a corruption of *athelida*, which was a corruption of *alhidada*.

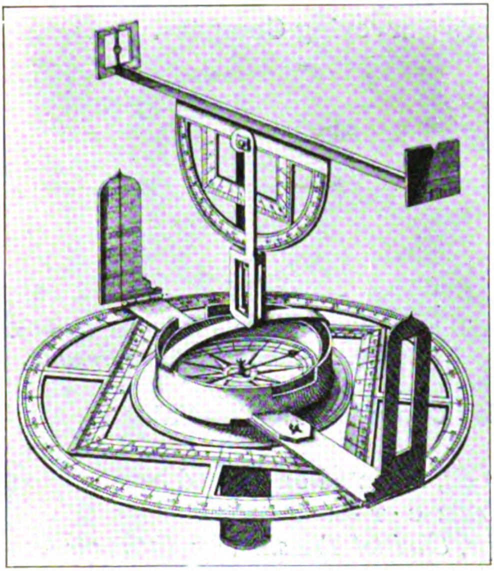
[2] *Pantom.* i. xxvii.

[3] *Penny Cycl.* (1842), *N. E. D.*

[4] *Surv. Dial*, pp. 111, 127.

range of the objective of his fire. This early association of the chief topographic instrument with accurate gunnery is preserved in the name of our State Survey Maps which are still known as Ordnance Survey Maps, although happily they are now less needed for military purposes than for those of peaceful possession of landed proprietors.

The next representation of an early form of theodolite is that given in Blaeu's atlas and presumably manufactured by him at Amsterdam. The construction of



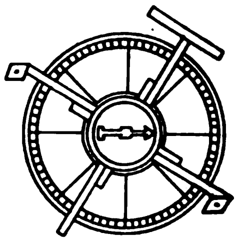
THEODOLITE.
Blaeu, Atlas, 1664.

Blaeu's theodolite was practically the same as that of Digges, although it was about eighty years later. It included all the parts of Digges's theodolite with the addition of a magnetic compass and of improved sights.

During the eighteenth century the ever-increasing need for accuracy in astronomical instruments led to the addition of great refinements of construction and to the superposition of auxiliary apparatus for the elimination

of errors of observation. The application of precise modern methods to the composition of a scientifically constructed theodolite is mainly due to RAMSDEN. This famous instrument maker had in 1763 invented a machine for dividing circles with greater precision than any that had hitherto been graduated. These circles and all the refinement of accessory appliances of the astronomical transit instrument, Ramsden introduced into a new theodolite, which was first used on the triangulation of England in 1787, when the triangulations of England and France were connected for the first time.

Tartaglia's Surveying Compass. 1520–60.



TARTAGLIA'S SURVEYING COMPASS, 1520-60.
Laussedat, *Recherches sur les Instruments.*

Surveying Compass and Sundial. 1608.
L. Evans Collection.

Brass Gilt, mounted on a wood base.

Inscribed: C · T · M · F · 1608.

Perhaps, *Christof Tressler* (*der Elter*) *me faciebat.*

The Diagonal Scale on the $12\frac{3}{4}$ inch sight-rule of this instrument has been already described in the part on *Mathematics*, p. 170.

268. Circumferentor or Surveying Compass. c. 1690.
Brass. Orrery Coll. 15.

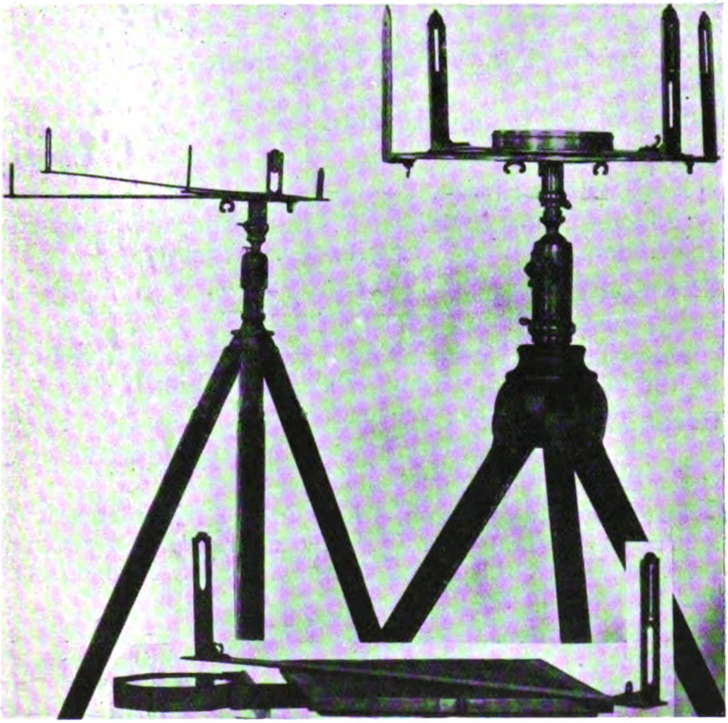
I: Worgan fecit.

The circular base-plate is 13 inches in diameter, with a border divided into $\frac{1}{2}$ degrees; two slit-and-thread sights are carried at the 0° and 180° marks.

An alidade with the second pair of similar sights bears

a centrally placed compass box with a 4 in. needle. It is pivoted in the centre of the circle.

The instrument is provided with a socket for attachment to the ball-and-socket head of an oak folding tripod. The legs are 2-jointed for portability, and the upper end is expanded like that of the tripods figured in Stone's *Bion Math. Instr.*, p. 128, and by Leybourn.



No. 270. Graphometer, *c.* 1690. No. 268. Worgan's Circumferentor, *c.* 1690. No. 271. Plane-Table with Alidade, 1696.
In the Orrery Collection at Christ Church.

Circumferentor or Surveying Compass. 1612.

L. Evans Collection.

Marked LVD · SEM · FEC · A · D · 1612

Circular plate $5\frac{1}{2}$ inches in diameter. With four pillar-like sight vanes rigidly fixed at right angles.

Circumferentor or Surveying Compass. **1679.**
L. Evans Collection.

'IOHANNES THVRNNER FECIT PRAGAE 1679'.

Brass gilt.

With small compass, $1\frac{1}{4}$ inch diameter, mounted on gimbals, and furnished with two sight vanes only.

Circumferentor or Surveying Compass. **c. 1720.**

Brass. L. Evans Collection.

'Made by Tho Wright Instrument maker to y^e^ PRINCE'.

Base-plate 1 foot in diameter.

Theodolite. **c. 1737.**

By Jonathan Sisson.

'The best, most complete, handsome and well designed Instrument possible.' Lawrence, *Surveying*.

Theodolite. **17—.**

By Heath.

Described in Hammond's *Surveying* ('wrote in reality by the late very ingenious Mr. Samuel Cunn').

Great Theodolite. **1787.**
No. 53 Royal Society.

By Ramsden.

Used by Major-General Roy in the trigonometrical survey of England and Wales, and presented by King George III to the Royal Society. *Phil. Trans.* lxxv and lxxx.

5-in. Theodolite. **17—.**
No. 57 Royal Society.

By Adams.

269. Theodolite. **c. 1834.**
University Observatory.

By Troughton and Simms.

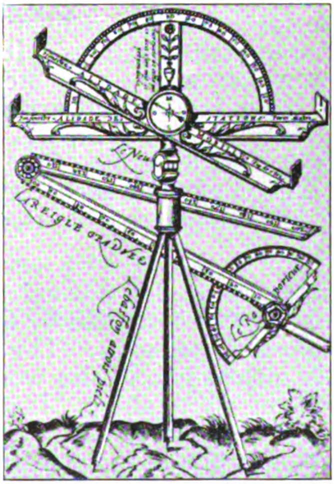
With 5-inch circles. Telescope 1-inch aperture, 10-in. focal length. Pattern described in Simms' *Treatise on the Principal Math. Instruments used in Surveying*, 1834.

In *Some Directions for observing with Troughton's Reflecting Circle*, 7 pp., 8vo, printed by C. Rickaby of

Peterborough Court, are described the three adjustments of which the instrument is capable. The concluding sentence is characteristic of the time: 'Should these hints about the adjustments set any over-handy gentleman on tormenting his instrument, it will not be what was intended by them.'

The Plane-table

The history of Plane-table methods has been told by an able exponent of its use, Mr. Reeves, F.R.G.S. By plane-tabling a graphic representation of a country can be obtained without the necessity of trigonometrical computations. The method of laying out angles by direct observation is of so simple a nature that we



Danfrie's Graphometre, 1597.
From Laussedat's Recherches sur les instruments.

cannot but believe that it was familiar to the early Greek geometers, and was used by them for constructing plans.

However, in reconstructing the history of our modern methods we can go no farther back than 1597, when one Phillip Danfrie of Paris invented the **Graphometre.**

The Graphometre consisted of two alidades, one fixed

with a graduated semicircle of degrees attached, the other movable. Both were fitted with slit and pin-hole sights. The observed angle between the alidades could be directly transferred to and drawn on a plan either by the superposition of the instrument, or else by means of a graduated and hinged rule which is also shown in the engraving of the Graphometre.

The Graphometre was supported on a portable tripod by a ball-and-socket joint and a hinge, by inclining which either horizontal or vertical angles could be observed.

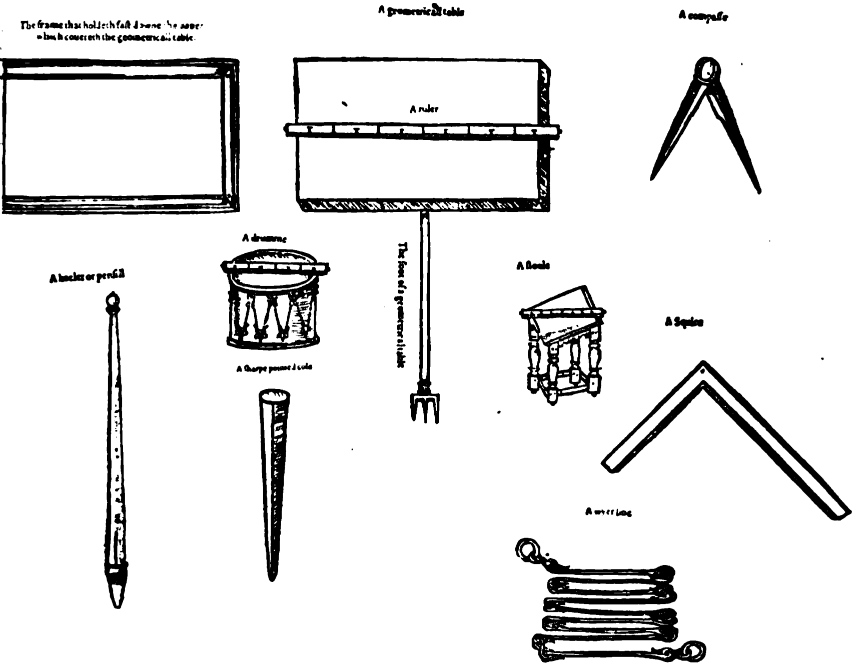
270. Graphometer or Surveying Semicircle. c. 1690.
Orrery Coll. 50.

With folding tripod stand 4½ feet in height.

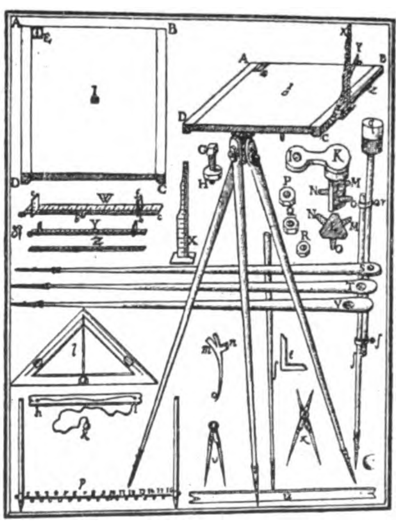
The semicircle (2¼ inches in radius) is divided into degrees numbered in both directions. It is fixed to one of the arms on which works a pointer, 10 in. long, attached to the other arm. Both arms are furnished with sights and are graduated into parts that are a trifle shorter than modern millimetres. The head is fixed to a ball-and-socket joint with socket attachment to a staff, so that the instrument can be used for observing angles in any plane.

The **Plane-table** appeared in a wonderfully complete form about 1590. It was described by CYPRIAN LUCAR in *A Treatise named Lucarsolace*. The contemporary engraving of this instrument, in the work of a mathematical professor in Wittenberg, JEAN PRAETORIUS (1537–1616), shows it mounted on a portable tripod with much accessory apparatus, including a magnetic compass, two alidades with sights, a plumb line, a plumb level (a plumb bob on a triangle), levelling staff, apparatus for measuring a base line, a vertical scale for measuring altitudes and the ordinary drawing instruments, dividers, proportional compasses, square, rule and curve (?).

Truly Praetorius would not have learnt much from a modern plane-table, though he doubtless would have appreciated the convenience of the spirit level and the increased accuracy accruing from the application of a small telescope to the alidade.



LUCAR'S GEOMETRICALL TABLE, 1590.



PRAETORIUS' PLANE-TABLE, 1590.

Cyprian Lucar informs us that

'Geometricall tables with their feete, frames, rulers, compasses and squires are made and sold by Iohn Reynolds, dwelling right against the southeast end of Barking churchyard in Tower Streete within London—and by Iohn Reade and Christopher Paine, dwelling in Hosier Lane neere unto West Smithfield in the suburbs of London.

'Wyer lines, like to that above mensioned, may be bought in Crooked Lane neare unto East cheape in London.'

Several of the surveying books of the period were illustrated with attractive pictures which showed how the 'Ichnography' of a region could be readily plotted by plane-tabling.

271. Plane-table. **1696.**

Orrery Collection 18.

$13\frac{1}{2} \times 10\frac{1}{2}$ inches, with Compass in a wooden bracket at one side.

The printed compass-dial is printed with the name of the maker, 'Iohn Worgan Londini fecit, 1696', and the frame is stamped with fleurs-de-lys in groups of three.

The table is surrounded by a removable, hinged, jointed frame of boxwood, graduated on both sides in degrees and scales of inches, which serves to fasten a sheet of paper upon the table.

The alidade, 22 inches in length, is provided with two removable slit-and-thread sights.

Both sides are engraved with scales between the sights. On the upper side are an 8-inch plotting scale, plain scales of $\frac{1}{10}$, $\frac{1}{16}$, $\frac{1}{20}$, $\frac{1}{24}$, $\frac{1}{32}$, and $\frac{1}{40}$ inch: on the under-surface are three scales, Gunter's line of Numbers and lines of Sines and Tangents.

The table is mounted on a ball-and-socket joint, with a clamping screw, and can be fixed by a socket to the end of a staff.

Cf. Stone's Bion *Mathematical Instruments*, p. 126.

Alidades for Plane-tables. **18th cent.**

L. Evans Collection.

A 2-foot and a 1 ft. 9 inch Alidade marked 'B. Scott fecit', and engraved with plotting and diagonal scales.

Cyprian Lucar informs us that

'Geometricall tables with their feete, frames, rulers, compasses and squires are made and sold by Iohn Reynolds, dwelling right against the southeast end of Barking churchyard in Tower Streete within London—and by Iohn Reade and Christopher Paine, dwelling in Hosier Lane neere unto West Smithfield in the suburbs of London.

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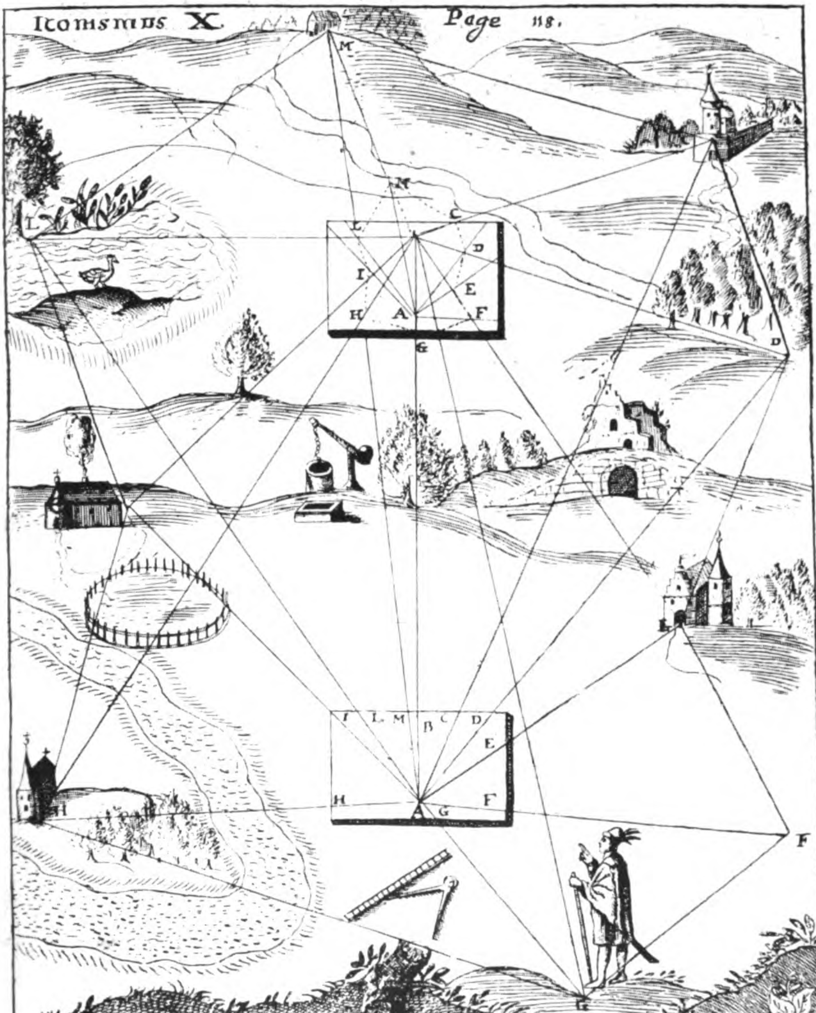
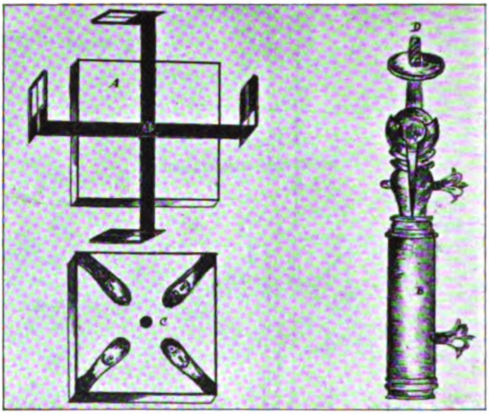


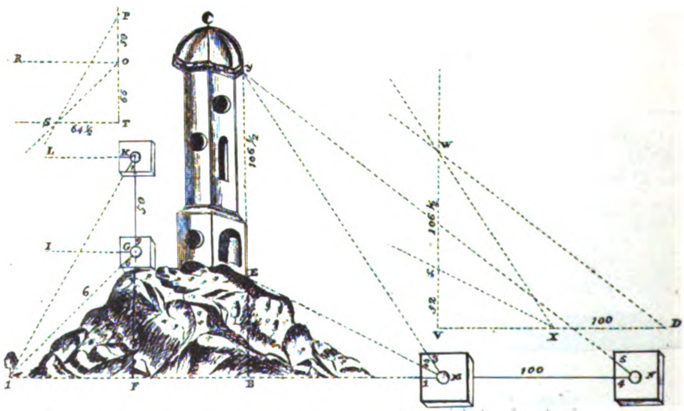
PLANE-TABLING IN 1660.
After Schott, Pantometrum Kircherianum.

1 foot 3 inch Alidade with diagonal scale. **1748.**
By *J. A. Hallensen icte et Pract: des Sciences Mathematiqu: Inventeur les ac fait . Wolfenb. 1748.*

1 foot 9 inch Alidade. Sight vanes missing. **17—.**
By *Langlois à Paris aux Galleries du Louvre.*



Douglas' Infallible, 1724.



The Infallible used for measuring the height of a Tower.
J. Douglas MS.

The Infallible. **1724.**

By J. Douglas.

The Infallible exists only in a manuscript description formerly in the possession of Mr. Reeves, who reproduced figures which show the construction and utility of the instrument. We are obliged to the Royal Geographical Society for the use of Mr. Reeves' illustration to his *Maps and Map-making.*

Scalae Agro-graphico-metricae, &c. **c. 1670.**

L. Evans Collection.

W. Hayes at the cross Daggers in Moore feilds Londini fecit.

Invented by I. Wybard *c.* 1645 and described in his 'Scalar Supplement' 'for the most accurate plotting of land', pp. 421–9 to the 3rd edit. 1674 of Leybourne's *Compleat Surveyor.*

DATED AND SIGNED EXAMPLES OF FOREIGN SURVEYING INSTRUMENTS OF THE SEVENTEENTH AND EIGHTEENTH CENTURIES

German

ANDREAS ALBRECHT		(Germ. Mus. Nuremberg)	1625
CHRISTOFF KÖHLER MECH. VON DRESTEN FECIT			1663
BAUMANN	Circumferentor	Stuttgart	
MICHAEL SCHEFFELT	Graphometer	Ulm	1719

Dutch

C. METZ	Circumferentor	Amsterdam	*c.* 1700

Flemish

G. MEURIS		Brussels	1681
		(Cons. Arts et Métiers, Paris)	
IODOCUS DEENS LOUANIENSIS BELGA AUSTRIORUM VIENNES FECIT			
		(S. K.)	1682

French

MICHAEL COIGNET		Paris	1606
		(Cons. Arts et Métiers, Paris)	
CHAMBÉRY	Circumferentor	Paris	1750
MEURAND	Graphometer	„	1780
GOURDIN	„	„	1785

Italian

JACOBUS LUSUERG	Mutinensis		1674
„ „		Faciebat Romae	1686
JOANNES MACARIUS di Mirandola (Modena)			1676
		(S. Kensington Museum)	
A. BALDANTONI	Alidade	Ancona	
F. CORRAZINI	Circumferentor		1747

APPENDIX A

The Orrery Collection at Christ Church

To the chance finding of these instruments locked up in a dark cupboard in Christ Church, all smothered with the dust of ages that had crystallized upon them, I owe the stimulus that has resulted in the Exhibition of Instruments in the Bodleian Library in 1919, in the printing of the present volume, and probably in the exhibition in Oxford of the superb collection of Instruments collected by Mr. Lewis Evans, F.S.A., and now offered by him as a gift to the University.

By permission of the Governing Body of the House I examined their collection, and at the request of the Dean, presented the following report.

I am grateful to the Governing Body of CHRIST CHURCH for giving me a unique opportunity of examining their very precious collection of scientific instruments, both because I am greatly interested in the construction of early instruments and because I have in hand an attempt at a history of the early study of practical science in Oxford.

In return, I beg that the Library will accept the enclosed catalogue of their property, with references to the literature of the more important pieces of apparatus.

The greater part of the collection has the special interest of being a one-man collection, and that man was the great-nephew to Robert Boyle. The oldest piece is dated 1658, and the greater number of instruments appear to have been acquired between 1690 and 1710. It may well be that in the Orrery collection, Christ Church has the largest, if not the only considerable collection now in existence of scientific apparatus formed by any one person who lived so long ago.

CHARLES BOYLE, fourth EARL ORRERY, like a recent Duke of Marlborough, was a wealthy scientific amateur, a patron of good work rather than an original investigator. The interest attaching to his collection is therefore not the interest that would now attach to the apparatus of a Robert Boyle, or of a Newton, or of a Galileo; but at the time it was probably

considered far more valuable than the rough-and-ready contrivances with which great discoveries are frequently made.

Its modern interest lies in its preservation of the best work of which the most skilful scientific craftsmen of the time were capable. Several of the instruments are likewise among the earliest of their kind still extant.

It appears that Lord Orrery died in August 1731. In September an inventory of his Scientific Apparatus was made by Thomas Wright, Mathematical Instrument maker of Fleet Street, whose name-plate appears on the Orrery in the Library. All these instruments, with his books but without his original Orrery, were bequeathed to Christ Church, who apparently agreed in their receipt for the apparatus sent to Eustace Budgell, Secretary, to keep them 'apart and by themselves in some separate room to be ever so preserved for ye use of those students or scholars that did or shall belong to our Society in such manner as we are directed to doe by ye last will and testament of the said late Earl of Orrery'.

Dr. Fanshawe appears to have conducted correspondence on behalf of the House.

With the aid of Wright's inventory I have been able to identify with certainty the greater part of the collection. The nature of the apparatus leads me to believe that it was mostly purchased before 1710, when Orrery would have been thirty-four years of age. Two of his microscopes may be considered to date from 1702 and 1704 respectively, when he would have been about twenty-six or twenty-eight years old. The oldest quadrant of 1658 is of a type with which Wren and Robert Boyle would have been familiar.

The following items seem to be of especial interest :—

Two telescopes with eight- or nine-draw vellum tubes, which are wider towards the eye-piece end.

The earliest English Compound Microscopes of Wilson [1702], and Marshall [1704].

The auxiliary appliances for both instruments seem to be absolutely complete; the latter may be a unique possession.

Four fine Planetaria by John Rowley illustrating the differences between the Ptolemaic and Copernican Theories of the Solar System.

An exquisitely finished silver model of the Copernican Sphere in a casket, by the same fine maker.

Various highly finished mathematical instruments by Rowley—the best instrument-maker of his time.

[Then followed a note on the Christ Church Orrery, the gist of which is printed in vol. ii, p. 269, and Thomas Wright's Inventory addressed To the Rev^{d}. John Fanshawe at Christ Church College, Oxon, who evidently received the collection.]

An INVENTORY of the MATHEMATICALL INSTRUM^{ts}: in the Library of the R^{t} Hon^{le}: y^{e} EARL of ORRERY Deceast.

In the Small Room

			PAGE
1.	*Two* WIRE SPHERES	vol. ii.	265
2.	A MAGICK LANTHORN *Six Figures*		*Missing.*
3.	A DIALLING SPHERE	vol. ii.	144
4.	*A small* QUADRANT *of Ivory on a Pedestall*	vol. ii.	179
5.	*A Three inch* BALL *on a Pedestall*		125
6 ?	A MICROMETER	vol. ii.	309
7.	*Two Brass* SPHERES, *one according to* COPERNICUS *the other according to* PTOLEMY	vol. ii.	266
8.	A MICROSCOPE *on a Stand*		285
9.	A CONCAVE GLASS *on a Stand* 10 *inches diameter*		281
10.	*A Brass* GLOBE *in a Frame & Stand* 5 *or* 6 *inch: diameter*	vol. ii.	264
11.	*A Silver* SPHERE *in a Lignum Vitae Case*	„	267
12.	*A small* REFLECTING TELLESCOPE *on a Stand. New Fashion*	„	314
13.	*A Pair of* 3 *inch* GLOBES *w^{h}. Brass Horrisons & Frames in a Case*		*Missing.*

In the Next Room

14.	*A Vellom* TELLESCOPE 8 *feet long*	vol. ii.	304
15 ?	*A Strong* STAFF *w^{h} a Ball & Socket & Balls to y^{e}* 3 *Leggs*	vol. ii.	308
16.	*A Square* WOODEN TELLESCOPE 7 *foot* ½ *Shutt brass ends*	vol. ii.	308
17.	*One Dtt^{o}* 5 ½ *feet Shutt Wooden ends*	„	307

In the Great Room, the first Drawer

18.	*A small* PLANE TABLE, *Ball & Socket, & a brass Index and Sights*		374
19.	*An Ivory* COMPASS BOX		*Now missing.*
20.	*A Pr of* PROPORTIONABLE COMPASS, *Silver in a Shagreen Case*		136

PAGE

21. *A Square 6 inch Silver* RULE, *a pair of Compasses of Silver at one End, a Pencell att the Other End* 136
22. *A 9 inch Ivory* SLIDING GUNTER 158
23. *A Box* SCALE
24. *A small Box wth 9 peices of Brass I believe relating to Gunnery* 146
25. *Two* MAGNIFYING GLASS *wth Handles*
26. *A small* MICROSCOPE *of Ivory* 284
27. *A Silver* TELLESCOPE *eight inches shutt* vol. ii. 306
28. *One Dtto: of Fishskin wth Ivory ends 2 Feet* ,, 304
29. *Four other* PROSPECTS 3 *wth Silver ends one without* [*Three missing*] ,, 299
30. A COMPOUND MACHINE *on a Stand wth ye 3 Weights* 222

The Second Drawer

31. A SPIRIT LEVELL *in a Fishskin Case* 329
32 ? A SKY OPTICK 280
33. A LOADSTONE *sett in Silver 2 inches square* *Missing.*
34. *A Silver Case of* INSTRUMENTS $4\frac{1}{2}$ *inch wth a small* SECTOR *two pr of* COMPASSES *& ye poynts &* DRAWING PEN *in a plain Shagreen Case* 134
35. *A Brass* SCALE *in a Case* 140
36. *A round* LEVEL *of Brass* 329
37. A SUTTONS QUADRANT *on Board* vol. ii. 177

The Third Drawer

38 ? *Two small* CAMMORA OBSCURA *one of Vellom* 279
39 ? *A sett of small* MICROSCOPES & OBJECTS *Missing.*
40. *A small pr of* SCALES *in a Case* 226
41. *A* $4\frac{1}{2}$ *inch* SUTTONS QUADRANT *of Brass* vol. ii. 177
42. *A small pr of* HANDVICE *& a* GUN TOOLL
43. *A sett of* SOLLID BODYS *in Box* 124
44. *A Brass* STILLIARD BEAM 225

The Fourth Drawer

45 a, b. *A Fishskin Case with a* [a]*9 inch Ivory* SECTOR *Silver Joynt, an* [b]*Ivory* SCALE *with a Silver peice to slide along* 145, 147
46. [a]A PARRELLEL RULE *an* [b]*Ivory* PROTRACTOR ; *& a sett of Compasses* 136, 137
47. *Two Silver* SECTORS *one 6 inch ye other 3 inch french* 145
48. *Three* PULLEYS *a Single, Double & Treble of Brass* 221

		PAGE
49.	*Two Brass* SEMICIRCLES	137
50.	*A Brass Head of a* STAFF, *& a Ball & Sockett.*	? 369

The above Inventory was taken by Tho. Wright, Mathematicall Instrument Maker Sept: 17th 1731

[N.B. The capitals, here used for clearness, are not in the MS.]

Other apparatus not included in Wright's Inventory, but believed to have belonged to Lord Orrery

Part of Oak Bracket with two pulley wheels, probably used for supporting the eyepiece end of the telescopes		308
Octagonal Marble disk, with one side ground concave, possibly used for polishing lenses		281
12-inch Sector by Allen		144

Later Acquisitions

Orrery. By Wright	vol. ii.	270
Dotchin with Ivory beam		224
Gunter's Chain of 66 feet or 100 links		163
Brass Protractor Diam. 12¾ in. By Sisson		137
Elliptical Trammel in T-shaped box. By Joseph Jackson		138
Parabolic Curve. A brass template. By Nairne & Blunt		139
Achromatic Refracting Telescope 3⅝ in. aperture. By Dollond	vol. ii.	312
Instrument box (empty) 'D.D. Franciscus Burton A.M. Alumnus'.		
Cuff Microscope in pyramidal box by Dollond		290
Cuff Microscope in pyramidal box by Adams		292
Turret Clock		235

APPENDIX B

Old Bodleian Catalogue of Cimelia Extracted from the Registrum Benefactorum

Phillipps MS. 13841

Anulus Astron. aeneus Sphaera aenea Quadrans Astron. aeneus Circini et Regul^{ae} Astron. aeneae	Sr Josiah Bodley 1601 See p. 168.

27° Mar. payed for bringing ye iron chest and ye brazen sphere from London 0.2.0. [Entry in *A Book of Accompts for y^e Librarie since S^r Thomas death A° 1613.* The book was purchased on 22 Oct. 1613.]

Insigne quoddam Instrumentum Mathematicum deauratum
S[r] Tho. Smith 1609

[Perhaps the Pocket Dial of Gilt Brass, which is not otherwise catalogued.]

An Alabaster Pillar representing ye 5 Orders etc.
Sir Clem. Edmonds 1620

[This is therefore far older than the date given on page 123.]

Turkish linen vestment (MS. Bodl. or. 162)
Richard Davydge, president of E I.C. 1653

Astrolabium Arabicum — Abp. Laud 1636

[No. 920 on p. 384.]

A Pair of Globes of Will. Blaeu's best edition
Tho. Chaloner 1657

A Crocodile from Jamaica — Dom. J. Desborow 1658

[A Case for Great Crocodile, 1671, 12*s*. *Bodl. Accounts.*]

Capsula conchis marinis, artificio miro ingeniosissime tessellata; Salamandra; Alia nonnulla Naturae mirandae — Rob. Southwell, Queen's 1657

Drake's chair — John Davies of Camberwell 1662

[Date 1668 is stated in the Benef. Register.]

Three large Pictt. of ye Muscles of a Human Body
Tho. Highlord Civis Londiniensis 1662

[Carriage cost 4*s*. *Bodl. Accounts.*]

Tubulus quo Nicotianae fumus hauritur.
Jeremiah Carter E. I. Mercht. 1663

[Carter was also a China merchant, and the pipe therefore probably Chinese. He also gave a Japanese fan and some Chinese brac-a-brac, enumerated in the Benefactors' Register. H.H.E.C.]

Duae bicubitales sagittae plumatae et ferro armatae Indicae; Duae aliae sesquispithamales ⟨ = 3 palms = c. 9 inches⟩ implumes cuspidibus ligneis barbatis et venenatis. — Henr. Thurscross E. I. Merch[t] Lond. 1666

Balaena in Sabrinâ fl⟨umine⟩ capta — Will. Jordan Apoth. Glouc[r]. 1672

Cranium Hibernicum usneatum [? = grown over with moss] [entered in Benef. Reg. under 1675, but noted by Bartholinus in the Anatomy School in 1663] — John Lamphire M.D. Princ. of Hart Hall 1675

Fragmenta lapidis in quo naturalis figura duorum Piscium; Frustulum Lapidis Asbesti; Conus cedri ex Monte Libano; Mummiatum cadaver — Aaron Goodyear Turkish Merch[t]. 1681

Calendarium ligneum perpetuum ligni quadrati angulis incisum more antiquo [a Clog almanack].	Rich. Davis A.M. Sandford, Oxon 1682?
Sceleton Humanum motionibus naturalibus mobile Pellis Humana infereta Pueri Nigritiae corpus integrum exiccatum. [Perhaps this is No. 190 of the Anatomy School.]	Sir Robt Viner Kt. & Bart, Lord Mayor of London 1683/4

Other early acquisitions, not entered in the Benefactors' Register

3945 Quadrans aeneus magnus curioso opere elaboratus. Ex dono Is. Vossii viri summi.
[Possibly Schissler's Quadrate, see p. 340.]

3205 Selden's Astrolabe (MS. Arch. Selden A. 71 (2)).

3206 Chinese compass 'Pixis sortilega Sinensium' (MS. Arch. Selden A. 71 (2)).

Items in the Old Catalogue of 1697[1]

The numbers are those of the Catalogue of the Laudian Collection.

911. Pocket Clog Almanack. Pres. by Laud in 1636. Now in glass case.
914. Perpetual Calendar (MS. Laud. misc. 753).
916. Telugu Almanack (MS. Laud. or. e 1 (R)).
918. Javanese Land instrument (MS. Laud. or. a 1 (R)).
920. Astrolabe, given to Laud by Selden. Presented to the Library in 1636.
921. Magic staff, described in Macray (*Annals*, 2nd edit., p. 84) as being of 'dark polished wood 2 ft. 9 in. long, with a grotesquely-carved figure at the head, apparently of Mexican workmanship'. Lost for some years.

2989 c. Horologium solare Cylindricum charta impressum. Mr. Craster informs me that this is 'not now found', but I should like to identify it as the printed scale for a cylinder dial that is still in the Library, which is described on p. 123 of vol. ii.

In 1694 the Anatomy school was visited by H. L. Benthem and on 19 August 1710 the state of the Bodleian Instruments was reported on by Z. von Uffenbach, *Reisen*, p. 100.

[1] This list was communicated to me by my friend Mr. Craster who has also drawn my attention to several Bodleian curiosities not ordinarily exhibited to the public.

On a table in the window stood a few measuring instruments, well made in brass and perforated, which lay about a 5-cornered column of alabaster, on the top of which was a **Polyhedron.** There was also a **Globus armillaris**, of brass on a wooden stand. In the stand was a cupboard, which Mr. Crab opened and showed us a very costly **quadrant** inside. It was said to be of pure gold.

For his description of this 'quadrant' see p. 340.

Eighteenth-century Accessions

Ovum Struthio-Cameli as Tabrè coelatum	J. Frederick Commoner of Univ. Coll.
8 Tabb. Anatomicae ab Amato Bourdono M.D. delineat. et aeri incisae Par. 1678	Chr. Willoughby D.D. Fell. of Magd. Coll. 1742
£70 towards the purchase of an Orrery	Rev. Jos. Parsons M.A. Merton Coll. 1760
Black negro baby preserved in spirits	A. Müller of Amsterdam 1818

[He is not now in the Bodleian Catalogue, but he may be behind some books somewhere.]

Other Miscellanies, in the Library in 1923

Runic Primstaff 1690–1700.
Perpetual Calendars in the form of tokens.
Hebrew " " "
Calendar for 1753 " "
Abacus. ? Rawlinson Bequest. See p. 126.
Two Wooden Locks. One with printed label, 'No. 13'.
Iron Padlock and Key.
Matchbox with original label : 'Congreve Matches from the most celebrated manufactory in Germany I.N.E.'
? Cidaris Spine and two Fossil Shells.
Wire of Foucault's Pendulum in the Radcliffe Camera.
Chinese Goldsmith's Steelyard with printed label 'No. 11'.
Collection of Moss Agates.
Two Bladder Stones and a fragment of a third. 36601 MS. English. 1593. Now MS. Engl. misc. d. 80 (R).
Papyrus plant, in its natural state.
Hair from *Homo sapiens* L.

The specimens have been collected from the following individuals: an unknown Egyptian lady, whose skull is also in the Library (in the Bible Case), John Hampden, *d.* 1643, Keats, R. L. Stevenson, P. B. and Mary Shelley.

These, and the other old biological collections of the University, will, it is hoped, be further described in a third volume of this book.

The Anatomy School and the Savile Study

The description of the contents of the Anatomy School is deferred until the printing of a further volume dealing with the Biological Studies of the University. But it should always be remembered that a large part of the space now occupied by the University Library has been gained by the sacrifice of the historic interests of several of the more important Scientific Schools of the University. The transference of the Anatomy School to the Bodleian (*c.* 1789–1805) has been a real loss to the history of Medical Science in Oxford: the theft or loss of the Savilian instruments has not been less hurtful to the chronicler of Astronomical studies. At the same time it must be remembered that many of our historic instruments owe their preservation to having been deposited in a Library, and not in a Laboratory.

Until 1834 the Savilian Professors of Astronomy and Geometry enjoyed the use of a small room in the south-east corner of the Schools Quadrangle. It is possible that one of the four corner-staircases, that figured in the original plan, was removed, floors being introduced, and a space nearly five yards square, less a new narrow stairway, was fitted as a repository, the 'Savile Study', for the Savilian Books and Apparatus. Those instruments that existed in 1697 are listed in vol. ii, p. 79.

The fine old book-presses, books (many of them stamped on the back with the monograms of Savile and Wren), and a table, are still there, and, until 1919, when it was moved to the Gallery, also the strong box, the 'Cista Mathematica' (p. 122), now quite empty. The only pieces of the old apparatus that remain, are two wooden spheres, p. 125. And these have survived because they never had any special intrinsic value!

APPENDIX C

Notes on the decorative stampings on leather and vellum work

The stamped ornamentation on the tubes of early telescopes and microscopes and on cases of instruments introduces us to the intricate subject of bookbinders' stamps and to the craft of the leather-worker and gilder. In this difficult matter, I have had the benefit of the wide experience of Mr. Gordon Duff, who has recognized among the stampings several of the characteristic forms of the seventeenth century, but has also pointed out certain others new to him, which in his opinion were not made with ordinary bookbinders' tools; these last include some stamps on tubes of somewhat late date which we know to have been sold by John Marshall; but on the other hand Mr. Maltby, the Oxford bookbinder, is prepared to accept all as the work of a bookbinder, perhaps of a man in a small way of business.

There are perhaps conveniences in treating of these stampings all together in one place rather than under the several instruments. We have noted stamps on the following articles:

1. Case of Surveying Compass by Worgan, p. 368.

   The stamps, fan shaped, ammonite shaped, and sun shaped, are all of the pattern of those which were ordinarily used by bookbinders in the second half of the seventeenth century.

2. Large vellum Telescope tube, probably by Marshall, vol. ii, p. 305.

   This fine piece of work is decorated with light foliated and floral stamps and acorn designs in the corners and with a 'cat-tooth' border, all made with bookbinders' tools. The work resembles the stamped vellum bookbindings which were very common in Holland in the seventeenth century, but it may quite well have been executed in London.

3. The draw tube of the Camera Obscura, p. 279.

4. The smaller vellum Telescope tube by Marshall, vol. ii, p. 304.

   Both these instruments were decorated with the same tools. The 'cat-tooth' border has been made with an ordinary bookbinders' wheel, but Mr. Gordon Duff is of

opinion that the larger stampings in the centre of the panels are not of a kind that were in common use among bookbinders, nor are the marginal devices, each containing a knotted snake and an acorn (?), of a kind that he has ever seen on bookbinding. It is therefore to be presumed that the tools used were either made specially for this kind of work, or, what is more probable, were those used by the craft of leather-workers for stamping boxes, shoes, and other objects.

The vellum is mottled with green and red blotches like those often seen on German bindings of the period.

5. The small Perspective Glass, vol. ii, p. 299.
   Stamped with diamond and fish-shaped designs which are not usual on bookbindings (Gordon Duff).

6. Perspective Glass belonging to the Royal Society.
   With *fleur-de-lys* stamps.

7. Small 3-draw Telescope marked *J. Howe, Londini fecit* *c.* 1700, p. 306.
   Decoration includes flowers in goblets grouped in diamonds within a solid cat-tooth border used both long-ways and round the tube.

8. Microscope by Marshall, p. 285.
   The outer body is covered with red leather with gold stampings. The oval central patterns, comprising three flowers and foliage in a vase, are made by two impressions from a tool, of a shape unusual in bookbinding (G.D.), as are some star and crescent stamps which would have been appropriate to a telescope tube. The solid cat-tooth border is used all round: a foliated scroll border is used long-ways.

9. Microscope by Marshall, in the possession of Mr. T. H. Court.
   From a rubbing which Mr. T. H. Court has kindly sent me, it is certain that, while resembling the Orrery microscope in general appearance, the gilt ornament has been impressed with quite a different set of tools. There are no stampings corresponding to the stars and crescents on the Orrery instrument, and the outer body of the tube is covered with green vellum instead of leather.

10. Case of Laudian Astrolabe in the Bodleian Library, vol. ii, p. 196.

APPENDIX D

List of Members of Colleges and Halls whose names are mentioned in this book in connexion with the study of Natural Science. Medical men and biologists are omitted.

The names of those who are especially distinguished by their scientific work are printed in clarendon type.

M.P.S. = Member of the Oxford Philosophical Society.

UNIVERSITY COLLEGE, 1249

Leonard Digges, d. 1571.
Edmund Cartwright, Fellow of Magdalen.
John Benbrigg, M.P.S. 1684.
Nathaniel Boys, M.P.S. 1683.
Richard Griffith, 1635?–1691. Fellow.
William Smith, 1652–1735. Fellow, M.P.S. 1683.
Hugh Todd, 1658?–1728. M.P.S. 1684.
Percy Bysshe Shelley, 1792–1822.

BALLIOL COLLEGE, *c.* 1265

Cuthbert Tonstall, 1474–1559. Mathematician, 'finding philosophers dominant, he migrated to Cambridge'.
William Barlowe, d. 1625.
John Evelyn, 1620–1706. F.R.S., Diarist.
John Keill, 1671–1721. Savilian Professor.
Nathaniel Crowch, M.P.S. 1684.
James Bradley, 1693–1762. Savilian Professor.
John Smith, 1744. Afterwards of St. Mary's Hall, q. v.
Sir George Shuckburgh-Evelyn.

MERTON COLLEGE, 1264

Thomas Bradwardine, *c.* 1290–1349.
Walter Brit.
*William Grizaunte, 1299.
Nicholas de Sandwych.
***Richard of Wallingford**, 1292?–1336.
Simon Bredon, M.D. 1330.
John Aschenden, 1338.
William Rede, *c.* 1325–1385.
John Maudith, *c.* 1340.
*Reginald Lambourne, *c.* 1350–1360.
William Merle.

* Not mentioned in Bursars Rolls.

John Chylmark, *c.* 1386.
John Killingworth, *c.* 1400.
Walter Hart, 1437.
John Curteis, 1444.
Henry Sutton, 1458.
Thomas Kent, 1490.
Sir Henry Savile, 1549-1622. Warden.
Anthony Wood, pupil of Sthael's, 1663.
William Coward, M.P.S. 1685.
Edmund Dickenson, *c.* 1640–*c.* 1705. Chemist.
Jonathan Goddard, *c.* 1612–1675. Warden.
Thomas Lane, M.P.S. 1684.
John Massey, Chemist. M.P.S. 1684.
William Noble, worked on Acoustics, *c.* 1670.
John Pointer, 1668-1754. Benefactor to St. John's.
Charles Willoughby, M.D. Padua. Chairman of Dublin Philosophical Society, 1683.
Charles Standard, M.P.S. 1685.

GLOUCESTER HALL, 1283

Thomas Allen, 1542–1632. Later of Trinity College.
Sir Kenelm Digby, 1603-1665. Chemist.
Theodore Haak, 1629.
James Pound, 1669–1724. Astronomer.

HART HALL, 1282–1740

John Caswell.
Joshua Dring.
J. T. Desaguliers, 1683-1749.

EXETER COLLEGE, 1314

Joseph Glanvill, 1636-1680.
Narcissus Marshe worked on Acoustics, *c.* 1670.
Stephen Rigaud, 1774–1839. Savilian Professor.

ORIEL COLLEGE, 1326

Samuel Desmasters, M.P.S. 1683.

ST. MARY'S HALL, 1326–1902

Thomas Hariot, 1560-1621. Mathematician.
Dr. John Smith, M.D., 7th Savilian Professor of Geometry, 1776-1797.
Basilius Nitikin, fl. 1769.

QUEEN'S COLLEGE, 1340

Sir Henry Wotton, 1568–1639.
Joseph Williamson, 1633–1701. First of Sthael's pupils in chemistry.
Edmund Halley, 1656–1742. Savilian Professor.
John James, undergraduate 1781.

NEW COLLEGE, 1379

Thomas Lydiat, 1572–1646.
Sir Henry Wotton, 1568–1639.
John Ballard, M.P.S. 1683. Fellow.
Henry Beeston, M.P.S. 1683. Warden.
William Musgrave, M.P.S. 1683. Fellow.
Francis Turner, member of Sthael's class, 1659. Fellow, Bp. of Ely.
John Lamphire, frequented Tillyard's Coffee House 1655.
Robert Sharrock, pupil of Sthael's, *c.* 1664.
Martin Wall, 1747–1824. Reader in Chemistry.
John Lucas, 1769.

LINCOLN COLLEGE, 1427

Joseph Glanvill, 1636–1680. Migrated to Exeter College.
Nathaniel Crew, 1633–1722. Pupil of Sthael.
William Deedes, M.D. 1691. M.P.S. 1685.

ALL SOULS COLLEGE, 1437

John Robins, 1500?–1558. Astrologer.
Robert Recorde, 1510?–1558. Mathematician.
John Mayow, 1643–1679. Chemist.
Christopher Wren, 1632–1723. Man of Science.
Timothy Baldwin, frequented Tillyard's Coffee House 1655.
William Bull " "
George Castle " "
Peter Pett " "
Thomas Creech, M.P.S. 1684.
Thomas Millington, attended Sthael's class, *c.* 1660.

MAGDALEN COLLEGE, 1458

Simon Forman, 1552–1611. Astrologer.
John Thornborough, 1551–1641.
Thomas Jeanes, attended Sthael's class, *c.* 1660.
Henry Yerbury " "
Alexander Pudsey, M.P.S. 1684.
Thomas Smith, " "
Thomas Ludford, " 1687
Servington Savery. Physicist. Inventor.
Gowin Knight, 1713–1772. Authority on magnetism.
Edmund Cartwright, 1764. Inventor.
Charles Daubeny, 1795–1867. Man of Science.

BRASENOSE COLLEGE, 1509

Sir Henry Savile, 1561. Migrated to Merton College.
Elias Ashmole, 1617–1692.
Sir W. Petty, 1623–1687.
Joshua Walker, M.P.S. 1684.
T. Robinson, M.P.S. 1686.
Sir Christopher Sykes, fl. 1760.
Hon. Thomas Noel, Sir Frank Standish, Bart. — gave £20 each for purchase of mathematical instruments for the use of the Library, 1767.

CORPUS CHRISTI COLLEGE, 1517

Nicholas Kratzer, 1487–1550? Astronomer.
Thomas Hornsby, 1733–1810. „

CHRIST CHURCH, 1546

Hon. Robert Dudley, 1573–1649.
Robert Fludd, 1574–1637.
Edmund Gunter, 1581–1626.
John Dwight, fl. 1671–1698. Inventor of Salt-glaze Stoneware.
Thomas Willis, 1621–1675. Sedleian Professor of Nat. Philosophy.
Robert Hooke, 1635–1703.
Richard Lower, attended Sthael's class *c.* 1660.
Benjamin Woodroff „ „
John Locke „ „
Henry Stubbe, Student, 1632–1676. 'A singular mathematician' expelled from Christ Church for writing against the clergy.
Thomas Whittal, Student.
Dr. Henry Aldrich, M.P.S. 1683.
Michael Evans, „ „
Maurice Wheeler, Chaplain, 1648?–1727.
Hon. Charles Boyle, 4th Earl of Orrery, 1676–1731.
John Freind, 1675–1728. Chemist.
Richard Frewin, 1681?–1761. Assistant to Freind.
Edward Hannes, 2nd Ashmolean Professor of Chemistry.
Whiteside, J.
John Kidd, 1775–1851. 1st Aldrichian Professor of Chemistry.

TRINITY COLLEGE, 1555

Thomas Allen, 1542–1632.
Ralph Kettell, 1563–1643.
Francis Potter, 1594–1678. Mechanician.
Dr. Ralph Bathurst. President of Phil. Soc. 1688.
George Bathurst.
Arthur Charlett, M.P.S. 1684.
Stephen Hunt, 'went a course of chemistry' 1683.

ST. JOHN'S COLLEGE, 1555

Nicholas Hill, 1570?-1610.
William Laud, 1573-1645.
Robert Fludd, 1574-1637. Afterwards at Christ Church.
William Levinz, studied chemistry under Sthael.
Edward Bernard, 1638-1696. Savilian Professor.
William Gibbon, M.P.S. 1683.
— Bonnie, M.P.S. 1686.
— Clare, 1769.

MAGDALEN HALL, 1602–1874

Jonathan Goddard, *c.* 1612–1675. Warden of Merton.
Edward Tyson, 1650–1708.
Robert Plot, 1640–1696.
John Young, fl. 1660.
Josiah Pulleyn, 1631–1714. M.P.S. 1683.
Anthony Farmer, fl. 1687. M.P.S. 1684.
William Levett, M.P.S. 1684.
James Higginbotham or James Price, 1752–1783. Chemist.

NEW INN HALL

John French, 1616?–1657. Distiller.

WADHAM COLLEGE, 1612

[Seth Ward, 1617–1689.] Of Sidney Sussex College.
Christopher Brookes, Manciple, fl. 1651.
John Wilkins, 1614–1672. Warden.
Christopher Wren, 1632–1723.
John Ludwell, Research on Glass-making, *c.* 1670.
Thomas Pigot, M.P.S. 1683.

PEMBROKE COLLEGE, 1624

Robert Cowcher, matric. 1675. Secretary to Philosophical Society.
Thomas Beddoes (1760-1808). Reader in Chemistry.

WORCESTER COLLEGE, 1714

— Bagly, M.P.S. 1684.
John Wall, 1708-1776. Founder of Worcester China Industry.
Robert Bourne, *c.* 1770-1829. Reader in Chemistry.

HERTFORD COLLEGE, 1740

George D. Yeats.

APPENDIX E

Letter of John Bird to the Astronomer Royal, relating to a chronometer by Harrison and containing the first mention of the projected Radcliffe Observatory.

Dear Sir. London 20th Aug. 1765

I did not write to you last Saturday because, then, I could only give you a partial account of our proceedings with Mr. Harrison. We have now spent five days with him, in great good humour; he first explain'd the drawings, then took the Watch to pieces and explain'd every part: the Contrivance is curious, and executed with great accuracy, but several parts are, and must be done by a tentative method, which will always render the execution tedious and difficult. It is kept going while winding up, by a Spring within the fusee, connected with the Great wheel: except this Spring it differs very little from common Watches till he comes to the Contrate wheel: this is curious, it contains the Spring (Spiral) which winds, by means of a detent, 8 times in a minute beyond this is nothing more than the ballance wheel and ballance, in which I include the ballance Spring which is regulated by a Thermometer: ~~which~~ this lies across the frame plate; and between the time of its comming from Jamaica and its going to Barbadoes, he added a Cycloid, or rather substitute thereof — The watch has no Slide. When I receive your money of Mr. Ibbetson I will lay it safely by, till you draw for it, or come to receive it — Pray help the Dean of Durham to rectify the line of Collimation of his Quadrant by a Star near ye Zenith, and you'll much oblige

Dear Sir yours Sincerely John Bird

Nothing yet about the Observatory at Oxford

John Bird and Dr. Maskelyne were members of a sub-committee appointed to make themselves acquainted with the mechanism of the historic watch, which won Harrison the prize for the determination of Longitude.

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Note. Part II has also been issued separately paged 1 to 101, instead of 87 to 187, the pagination adopted in this Index.

ANNOUNCEMENT

Volume I of EARLY SCIENCE IN OXFORD, including Part i, CHEMISTRY, and Part ii, MATHEMATICS, is now completed by the present double Part iii and iv, PHYSICS AND SURVEYING.

Volume II, ASTRONOMY, is in the press and will shortly be ready for issue to subscribers.

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